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# NASA Ames Aerospace Systems Directorate Research

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James A. Albers

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National Aeronautics and  
Space Administration



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James A. Albers, Ames Research Center, Moffett Field, California

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Space Administration

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## **SUMMARY**

The Aerospace Systems Directorate is one of four research directorates at NASA Ames Research Center. The Directorate conducts research and technology development, for advanced aircraft and aircraft systems, in intelligent computational systems and in human-machine systems for aeronautics and space. The Directorate manages research and aircraft technology development projects, and operates and maintains major wind tunnels and flight-simulation facilities. This report describes the Aerospace Systems Directorate's research and technology as it relates to NASA agency goals and specific strategic thrusts as developed by the Office of Aeronautics, Exploration and Technology of NASA Headquarters and by the NASA research centers.

## **INTRODUCTION**

The Aerospace Systems Directorate is one of four research directorates at NASA Ames Research Center. The Directorate is composed of five divisions, which consist of about 380 civil service employees and 360 support service contractors. In addition, undergraduate and graduate students, post-doctoral fellows, university faculty members, and military detailees support the activities of the Directorate.

The Aerospace Systems Directorate conducts research and technology development, for advanced aircraft and aircraft systems, in intelligent computational systems and in human-machine systems for aeronautics and space. Research includes the disciplines of aerodynamics, controls and guidance, flight dynamics, human factors, intelligent computational architectures, and artificial intelligence. The Directorate manages research and aircraft development projects, and operates and maintains major wind tunnels and flight-simulation facilities. Directorate activities involve a wide range of aircraft types including rotorcraft, powered-lift aircraft, subsonic and supersonic transports, high performance aircraft, and hypersonic and transatmospheric vehicles. A key characteristic of the Aerospace Systems Directorate is the ability to perform research at all steps of the aerospace research and development process—from the formulation of the initial concept through computer analysis, wind tunnel test, piloted simulation investigations, to flight research.

Many Directorate programs are conducted jointly with other agencies (national and international), private industry, and the academic community. For example, the Directorate has joint activities with the U.S. Army, Navy, and Air Force; the Federal Aviation Administration (FAA), the Defense Advanced Research Projects (DARPA), and with government research laboratories in Australia, Great Britain, Canada, France, Netherlands, and Germany.

The five divisions in the Aerospace Systems Directorate (fig. 1) are Aircraft Technology Division, Full-Scale Aerodynamics Research Division, Flight Systems and Simulation Research Division, Aerospace Human Factors Research Division, and Information Sciences Division. The Aircraft Technology Division provides a focus for vehicle-specific research, performs flight research, and carries out advanced vehicle conceptual design studies. The Full-Scale Aerodynamics Research Division conducts low-speed aerodynamics and rotorcraft aeromechanics research, and operates the

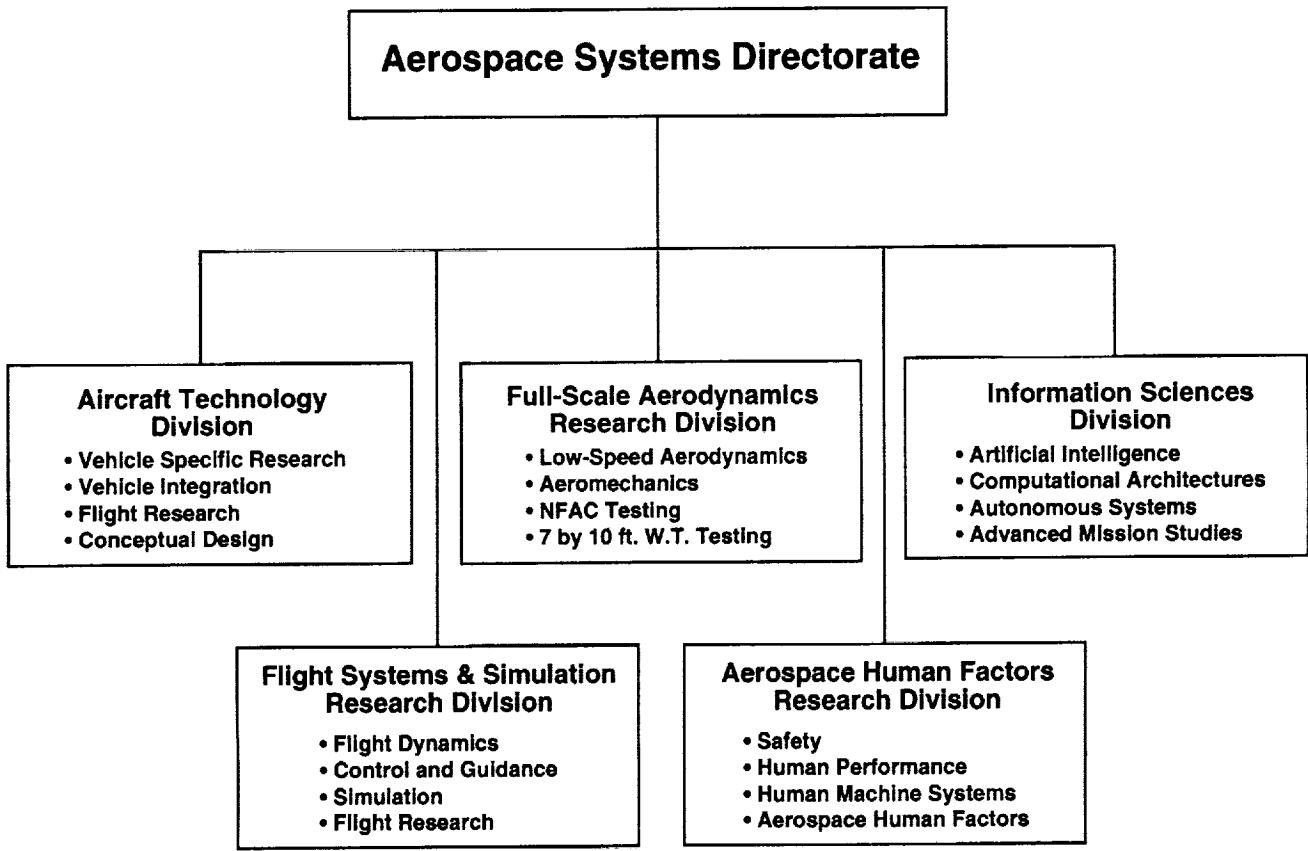


Figure 1. Organizational structure.

National Full-Scale Aerodynamics Complex (NFAC) and the 7- by 10-Foot Wind Tunnel. The Flight Systems and Simulation Research Division conducts research on flight dynamics and guidance and control, operates flight-simulation facilities, and performs flight research. The Aerospace Human Factors Research Division identifies and resolves human factor problems existing in aeronautics and space environments while emphasizing the improvement of safety, human performance, and human-machine systems. This Division also operates the Man-Vehicle Systems Research Facility (MVSRF). The Information Sciences Division conducts research in artificial intelligence, intelligent computational systems, and advanced missions (with specific emphasis on autonomous systems applications).

The quality of its staff is central to the Aerospace Systems Directorate capabilities. Over 84% of the staff has college degrees and many continue their education at local universities, as evidenced by the 60% of the technical staff that has advanced degrees. The Directorate has received such major national awards as the IEEE Award for Outstanding Achievement in Control Engineering, the AIAA Mechanics and Control of Flight Award, the 10th Theodore Von Karman Award, the AIAA Jeffries Aerospace Medical Research Award, the Royal Aeronautical Society Wright Memorial Lecture, the NASA Inventor of the Year Award, several NASA Space Act awards, and numerous other NASA

medals and awards. Each year about 280 NASA technical reports and papers are published, and several technical conferences and numerous workshops are sponsored by the staff.

This report describes the Aerospace Systems Directorate's research and technology as it relates to NASA goals and to specific strategic thrusts as developed by the Office of Aeronautics, Exploration and Technology (OAET) of NASA Headquarters and by the NASA research centers.



## NASA GOALS

NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration. To bring this vision to reality in the 21st century, NASA defined overall goals as reported in reference 1. The goals are to advance scientific knowledge of the planet Earth, the solar system, and the universe beyond; expand human presence beyond the Earth into the solar system; and strengthen aeronautics research and develop technology toward promoting United States leadership in civil and military aviation. The successful pursuit of these major agency goals requires commitment to the following supporting goals: continue to provide safe and reliable access to space and develop advanced space transportation capabilities; and develop facilities and pursue science and technology needed for the Nation's space program. As NASA pursues these goals the agency will promote domestic application of aerospace technologies to improve the quality of life on Earth and extend human enterprise beyond Earth. Also NASA will conduct cooperative activities with other countries when such cooperation is consistent with our national space and aeronautical goals.

The National Commission on Space (ref. 2) proposed a space goal for America in the 21st century which advocates that this nation lead in the exploration and development of the space frontier; thereby advancing science, technology, and enterprises. In 1989, the President approved a National Space Policy that updates and reaffirms U.S. goals and activities in space. This policy includes expanding human presence and activity beyond Earth orbit into the solar system.

The primary goal of the NASA aeronautics program is to maintain the preeminence of U.S. civil and military aviation by conducting research and technology that support development of superior U.S. aircraft and a safe, efficient, and environmentally compatible air transportation system.

Specific aeronautics and space strategic thrusts/goals have been developed by OAET and the NASA research centers. They are as follows:

### Aeronautics

#### 1. Subsonic Aircraft/National Aviation System

Develop selected, high-leverage technologies and explore new means to ensure the competitiveness of U.S. subsonic aircraft and to enhance the safety and productivity of the National Aviation System.

#### 2. High-Speed Air Transportation

Resolve the critical environmental issues and establish the technical foundation for economical, high-speed air transportation.

### **3. High Performance Military Aircraft**

Ready technology options for revolutionary new capabilities in future high performance fixed- and rotary-wing aircraft.

### **4. Hypersonic/Transatmospheric Vehicles**

Develop critical technologies to support ground and flight demonstration of the X-30 National Aerospace Plane and the development of future hypersonic vehicles.

### **5. Critical Disciplines**

Pioneer the development of innovative concepts, and provide the physical understanding and the theoretical, experimental, and computational tools required for the efficient design and operation of advanced aerospace systems.

### **6. National Facilities**

Develop, maintain, and operate critical national facilities for aeronautical research and for support of industry, Department of Defense (DOD), and other NASA programs.

## **Space**

### **1. Exploration**

Develop and demonstrate key technologies to enable the Nation's space exploration objectives. This includes technologies to increase reliability and reduce risk, and to reduce the cost and enhance capabilities for human and robotic exploration missions to the Moon and Mars, which will lead to a human expedition to Mars before 2019.

### **2. Space Station Freedom**

Develop new technologies for Space Station Freedom operations, evolution and growth to decrease life-cycle cost, and increase crew time available for performing experiments; develop new technologies to increase functional capabilities; and use Space Station Freedom as a laboratory for research and technology development.

### **3. Transportation Technology**

Provide, by the mid-1990s, technologies to extend the capabilities of current space transportation systems, and, during the 1990s, develop new technologies for next generation vehicle systems with emphasis on maintainability and operability, safety and reliability, affordability and performance.

**4. Science**

Develop advanced observation, information, spacecraft, and operations technologies to maximize the return from NASA space and Earth science missions during the next 20 years.

**5. Breakthrough Research**

Advance high-payoff, highly innovative technology concepts that could provide revolutionary improvements in space capability.

In the following pages research in the Aerospace Systems Directorate is delineated as it relates to specific aeronautics and space goals.



## **GOAL 1 AERONAUTICS—SUBSONIC AIRCRAFT/NATIONAL AVIATION SYSTEM**

**Develop selected, high-leverage technologies and explore new means to ensure the competitiveness of U.S. subsonic aircraft and to enhance the safety and productivity of the National Aviation System.**

Major challenges facing the Air Transportation System today include reducing congestion and delays, expanding system capacity, reducing community noise, and enhancing safety in the National Aviation System. NASA, in cooperation with the FAA, is directing its research toward meeting these challenges. In addition, NASA is developing technology to improve the international competitiveness of U.S. manufacturers. Specific research and technology areas follow.

### **Aviation Safety and Air Traffic Control Automation Technology**

Research in aviation safety and automation (in cooperation with the FAA) is intended to provide technology which, when applied to the aviation system, will result in safer and more effective operations. An overview of Aviation Safety and Automation Technology performed by the Directorate is given in reference 3. Major program elements include research in the areas of human-automation interaction, intelligent error-tolerant systems, and air traffic control (ATC) automation tools. The technology objective is for automation to assist humans in attaining increases in system safety and performance within the cockpit and at the ATC workstation.

The objective of the intelligent error-tolerant systems research is to develop and evaluate cockpit systems that provide flight crews with safe and effective ways to plan and replan flights, manage aircraft systems, and effectively respond to the external environment in dealing with contingencies. Research in intelligent error-tolerant systems includes evaluations of a normal flight-deck checklist, development of touch panel operated electronic checklist, and the development of a cockpit procedure monitor. In addition, display and warning systems research is under way in the areas of flight-deck information management systems, a traffic alert collision avoidance system, and three-dimensional (3-D) auditory displays. Design philosophy for human-centered automation is being developed and the effects of automation on pilots' performance and safety in advanced technology transports are being studied.

One system that will assist flight crew members in maintaining increased awareness of their external environment is the Traffic Alert and Collision Avoidance System (TCAS II). This system was evaluated by Directorate researchers in simulated air carrier operations (fig. 2). The study concluded that TCAS II can appreciably lessen the danger of air traffic collisions without imposing unacceptable increases in flight crew workload.

Three-dimensional auditory displays that provide spatial location of sound could serve as alternatives or supplements to visual displays. Initial studies on 3-D auditory displays indicate that they could improve situation awareness for both crew members and ATC controllers. The goal of this research is to develop a spatial auditory display that is both multipurpose and portable by synthetically generating localized acoustic cues in real time for delivery through headphones. Applications

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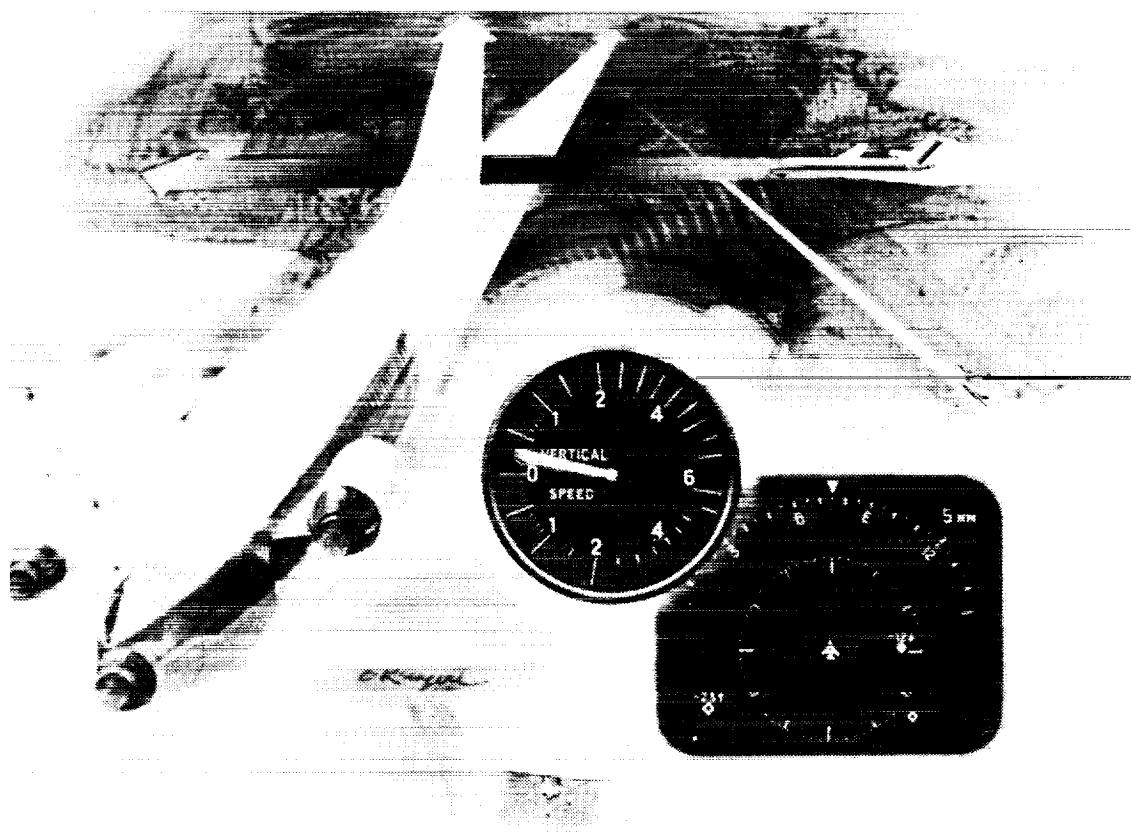


Figure 2. Traffic Alert and Collision Avoidance System.

for these displays include aircraft warning systems, traffic alerts, acoustic glide path and altitude deviation displays, aircrew and air ground communications, and ATC communications.

The Directorate, in cooperation with the FAA, has been conducting research to develop automation tools for assisting controllers in managing arrival traffic at both the Air Route Traffic Control Center (ARTCC) and at the Terminal Radar Control Facility (TRACON). Recently, this research has culminated in the design of an integrated set of tools which has been implemented in a network of workstations and is being tested in a real-time air traffic control simulation. The FAA is developing plans for field evaluations of these automation tools adapted to current ATC technology.

The integrated set of automation tools is referred to as the Center/TRACON Automation System (CTAS) because it provides both Center and TRACON controllers with an integrated set of tools for the efficient management and control of arrival traffic. Simulation tests conducted to date have demonstrated that CTAS permits controllers to make significant gains in both overall fuel efficiency and runway acceptance rate without increasing workload. CTAS is composed of three sets of integrated tools referred to as the Traffic Management Advisor (TMA), the Descent Advisor (DA), and the Final Approach Spacing Tool (FAST). TMA is designed for traffic managers in the Center and TRACON, DA for arrival and descent sector controllers in the Center, and FAST for feeder and final approach controllers in the TRACON environment.

The automation tools are investigated and verified in the ATC Advanced Concepts Simulation Laboratory (fig. 3). The laboratory provides a facility for real-time simulation of advanced ATC systems, using controllers and airline pilots as evaluation subjects. This unique laboratory has specialized software that allows rapid prototyping of ATC automation tools and a communications network (voice and data) connecting the Langley Transport Systems Research Vehicle (TRSV) simulator, the Ames Man-Vehicle Systems Research Facility (MVSRF) simulator, and the Denver ARTCC.

In addition to the previously mentioned research in aviation safety and automation, the Directorate has begun a research program that could lead to improved inspection of aircraft structures. The objective of the research is to develop, demonstrate, and implement an automated robotic inspection system for aircraft that will rapidly detect early signs of stress fractures, microcracks, and corrosion in aging or high-stressed aircraft. The proposed system will consist of four primary components: a magneto-optic imager, a data collection and analysis system, a graphic display, and a robotic surface-tracing system.

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Figure 3. ATC Advanced Concepts Simulation Laboratory.

Nondestructive testing techniques in use today by the aviation industry use visual and eddy current inspection techniques to detect cracks and corrosion around rivets, lap joints, and other critical areas in aging aircraft. These techniques are manpower-intensive, require a large amount of time to perform, and are limited in their ability to detect small fatigue cracks in rivets. The proposed research system is expected to have several advantages over current techniques. It will increase the detection rate of microcracks, including the detection of below-surface corrosion, and should decrease inspection time by at least 50%, while increasing the reliability and probability of fault detection. It should minimize, if not eliminate, the human errors associated with manpower-intensive data analysis and interpretation over long periods of time.

### **Advanced Rotorcraft Technology**

NASA's major role in rotorcraft is to develop and verify new design concepts, tools, and methodologies to improve vehicles, thereby reducing cost and increasing reliability and operational capability. The objective of the rotorcraft program is to develop technology that will provide safe, efficient, and environmentally compatible high-speed rotorcraft in the National Aviation System. In addition, the objective is to maximize the transfer of the research results to industry and other government agencies for civil development programs and planning efforts. This technology also provides spinoffs for military applications.

NASA/FAA/DOD-sponsored civil tiltrotor application studies were completed, which identified a large market potential, high-payoff technologies and benefits, and recommended actions required to implement a civil tiltrotor transportation system. Benefits include the ability to expand airport capacity, relieve ground and air congestion, rapid implementation and flexibility, and large export potential (ref. 4). An artist's concept of a 19-passenger civil tiltrotor configuration is shown in figure 4. An overview of research directed toward civil applications of rotorcraft is given in reference 5.

Current research areas in the Directorate include noise reduction technologies on advanced rotors, rotor/wing aeromechanics and integration, and vehicle systems and flight procedures. System studies are under way to assess the state-of-technology for advanced configurations and to identify the critical elements required for the technology base. This research focuses on configurations with performance attributes (primarily speed) that go well beyond the conventional tiltrotor. Performance attributes must be accompanied by safe, effective terminal area operations and by low noise.

The system studies are complemented by the development of analytical methods tailored to advanced configurations, and by wind tunnel testing and simulations to investigate deficiencies and advantages of leading configurations. A tiltrotor download reduction program is under way to develop validated design methods to minimize the download experienced by hovering tiltrotor aircraft. A program is under way to develop noise prediction methodology for next generation quiet tiltrotor aircraft and to quantify tiltrotor vehicle aerodynamic and acoustic interaction characteristics. Simulation investigations are being performed to develop vehicle requirements and terminal operating procedures criteria for safe, steep approaches and departures for potential implementation of tiltrotor aircraft in the National Aviation System.

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Figure 4. Artist's concept of civil tiltrotor configuration.

### Low-Speed Aerodynamics

Low-speed research is performed for many aircraft types including transports, rotorcraft, powered-lift aircraft, and high performance aircraft. Research areas of emphasis on subsonic transports include high-lift system aerodynamics, vehicle aeroacoustics, engine/airframe integration, and wake vortex alleviation. This area of research requires an integrated design approach for improved takeoff/climb and landing/approach aerodynamic performance and a reduced noise footprint. Innovative concepts will be evaluated and computational methods applied to develop and validate design methods to improve the performance and reduce the complexity of high-lift systems. In addition, wake vortex alleviation methods will be evaluated in the wind tunnel.

Engine/airframe integration and vehicle aeroacoustics will emphasize testing of a large-scale, ultra-high bypass turbofan engine in the National Full-Scale Aerodynamics Complex. The long-range objectives are to measure aerodynamic and acoustic performance, develop noise reduction concepts, and develop and validate computational analysis techniques leading to design methods to be used by U.S. industry for efficient, quiet, and competitive commercial transports of the future.

### Rotorcraft Human Factors

The Rotorcraft Human Factors Research Program was established to develop scientific data bases, principles, and conceptual designs to aid designers and users of military, public service, and civil rotorcraft in improving safety, expanding mission capabilities, reducing crew size, and optimizing training time and cost (ref. 6). Program elements include the development of (1) computational

models relating pilots' use of visual cues to control strategies, (2) design principles and training methods to improve pilots' abilities to fly with night-vision devices, (3) low-cost electronic map displays, and (4) methods of incorporating information about pilots' decisions and task-performance strategies into predictive models, measures, and certification standards.

Helicopter pilots perform increasingly diverse missions in environments that range from controlled airspace to remote and hazardous terrain. Vehicle control, navigation, communications, systems monitoring, and information integration impose significant and increasing demands on pilots, particularly during single-pilot operations. Although computer aiding and automation are being introduced, pilots are often overloaded during critical phases of flight. Human error contributes to 70-80% of all helicopter accidents.

An example of human factors research under way is technology to improve the safety of Emergency Medical Service (EMS) operations. NASA sponsored two government/industry workshops that resulted in an EMS Safety Network within the Aviation Safety Reporting System to serve as the primary reporting point for civil and public service medevac incidents. A prototype, low-cost electronic map display is being developed to aid EMS pilots in maintaining their geographical orientation. Directorate researchers have begun field studies and part-task simulation research to define human performance capabilities and limitations with night-vision devices.

The long-term goal of the rotorcraft program is to foster the transfer of research to the operational community. This is accomplished by evaluating principles and models developed in laboratory research in realistic simulation and flight tests and by developing cooperative programs with military and civilian helicopter operators and industrial organizations.

### Aircraft Operating Problems

For a number of years the Directorate has investigated various aircraft operating problems including flight encounters with severe atmospheric disturbances, and crew fatigue and jet lag. In addition, research is directed toward the development of an electro-expulsive separation system for de-icing aircraft surfaces.

Flight encounters with severe atmospheric disturbances such as turbulence and microbursts are continuing problems that must be better understood to improve safety. Data gathered from airline flight-data recorders have provided a detailed description and improved understanding of severe atmospheric disturbances, and have led to the development of mathematical models for use in piloted simulations (ref. 7). Investigations are planned in flight simulators to better understand control problems for severe turbulence encounters and to determine methods to reduce maneuvering loads.

Operational errors from long-haul flight crews can sometimes be attributed to fatigue and jet lag. The objectives of the research program are to determine the extent and effect of fatigue and circadian desynchronization on flight crew performance and to develop countermeasures to minimize the effects. Study results indicate that a preplanned rest period during low workload phases of flight (i.e., cruise) appears to act as a "safety valve" for sleep loss and fatigue that result from the multiple time zone changes and disturbed sleep associated with long-haul operations (ref. 8).

An electro-expulsive deicer has been developed, which is a low-cost, low-power, compact, and lightweight solution to the icing problem (fig. 5). The electro-expulsive deicer boot is readily bondable to almost any substrate, and requires no mechanical moving parts or pneumatic inflation to effectively shed ice from aircraft surfaces. It also has minimum aerodynamic penalty and has the potential to be retrofitted. The new deicer is an elastomeric boot that cyclically, expulsively expands and throws off any accreted ice (ref. 9). Icing wind tunnel tests and flight tests have demonstrated highly successful de-ice and anti-ice modes. This concept looks very promising for both rotorcraft and fixed-wing aircraft.

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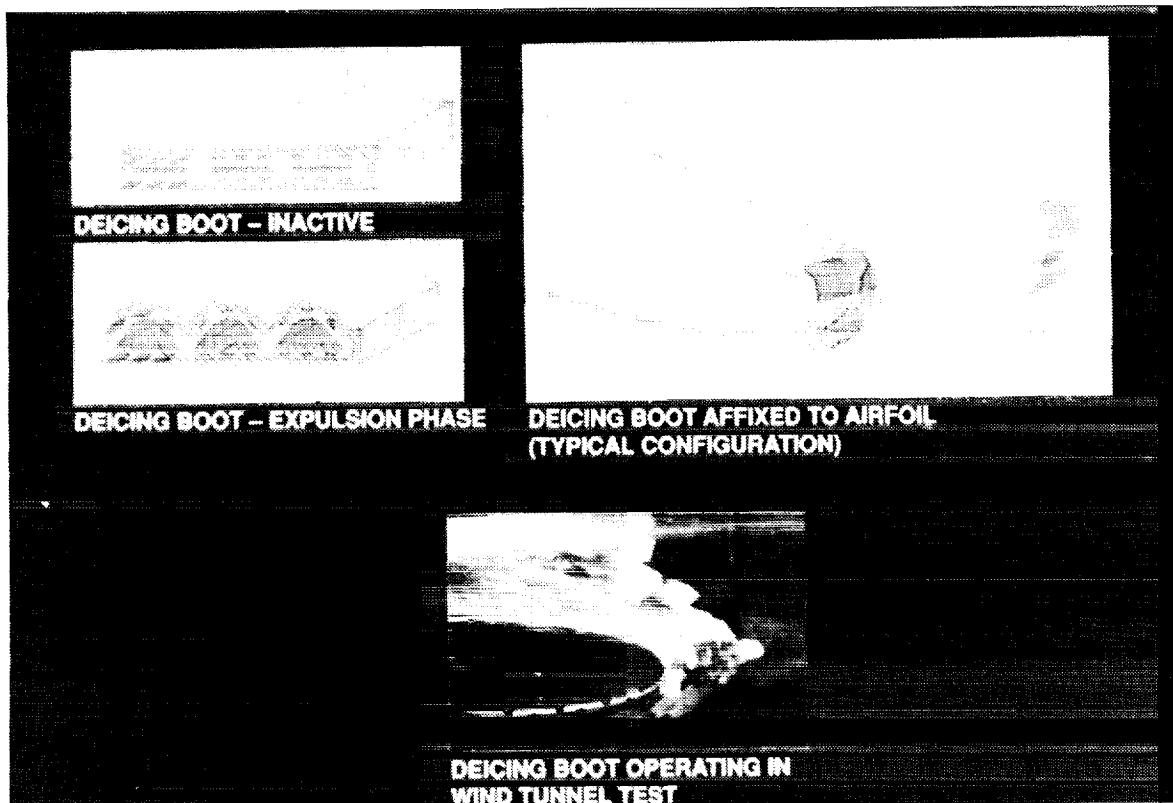


Figure 5. Electro-Expulsive Deicing System.

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## **GOAL 2 AERONAUTICS—HIGH-SPEED AIR TRANSPORTATION**

**Resolve the critical environmental issues and establish the technology foundation for economical, high-speed air transportation.**

The major objective of the High-Speed Research Program (ref. 10) is to provide solutions to the critical environmental barrier issues of atmospheric ozone depletion, airport noise, and sonic boom associated with a proposed high-speed civil transport (HSCT). Resolution of these critical issues will place the United States in a position to make informed decisions regarding follow-on technology development programs leading to industry commitment to develop and market an HSCT. Follow-on research will develop and verify the high-leverage technologies essential for economic viability of an HSCT.

### **Conceptual Design and Vehicle Integration**

The Directorate has the in-house capability to provide rapid parametric assessments of vehicle design variables, mission requirements and design constraints to guide the formulation of research programs. An aircraft synthesis computer program, called ACSYNT, is used to perform tradeoff studies that will identify technology developments that can provide a more environmentally acceptable and economically viable HSCT. The synthesis code allows interdisciplinary design issues associated with airframe/propulsion integration, community noise, and sonic boom characteristics to be addressed in an integrated manner for determining economic viability. The economic analysis includes vehicle cost, total operating cost, and revenue requirements for airline-type operations. These tradeoff and sensitivity studies indicate optimal parameter values and benefits of technology improvements, and guide the formulation of research and technology plans.

### **High-Lift System Aerodynamics**

The HSCT requires aerodynamic tradeoffs for the aircraft to operate efficiently in both subsonic and supersonic flight regimes. The highly swept wing design required for efficient supersonic flight makes it more difficult to design an aircraft with the necessary landing and takeoff performance characteristics. However, high-lift systems of highly swept wings have the benefit of reducing community noise through reduced power requirements and improved climb rates. A research program is in progress to develop concepts and design methods to improve the high-lift systems on supersonic transport aircraft. Small-scale wind tunnel tests will be performed to evaluate such promising high-lift concepts as the trapped vortex, separation control devices, vectored thrust, and advanced multi-element wing design. Planned tests at high Reynolds number and at flight Mach number will evaluate the most promising, practical systems.

### **Noise Reduction Technology**

The success of any future supersonic commercial transport directly depends on the reduction of jet noise during takeoff and landing to levels well below that possible with current technology. The objective of the ongoing research program is to develop the technology for the measurement,

prediction, and suppression of this jet noise. Aerodynamic and acoustic measurements will be obtained during tests in the 40- by 80-Foot Wind Tunnel and analysis methods will be developed to define the key aeroacoustic mechanisms that determine forward flight effects on jet noise. Selected jet-noise suppressor concepts will be evaluated at landing and takeoff speeds to determine suppressor aeroacoustic performance. Aeroacoustic scaling of these complex flows will be addressed by comparison of small-scale and full-scale test results.

### **Flight-Deck Systems and Control**

HSCT research activities will focus on developing and validating flight control, automation and cockpit systems technology to enable safe, all-weather takeoff and landing, integration into the National Aviation System, and optimal fuel/noise takeoff and landing. The research program will develop vehicle controllability requirements, integrated vehicle/propulsion control concepts, autonomous navigation/guidance concepts, and certification criteria. The program will build on our broad-based research and facility experience in low-speed terminal-area flight, and particular experience in supersonic transport certification criteria development.

Human factors research will develop and test a cockpit information system for the HSCT. The Advanced Concepts Flight Simulator (fig. 6) will be used to investigate advanced cockpit displays

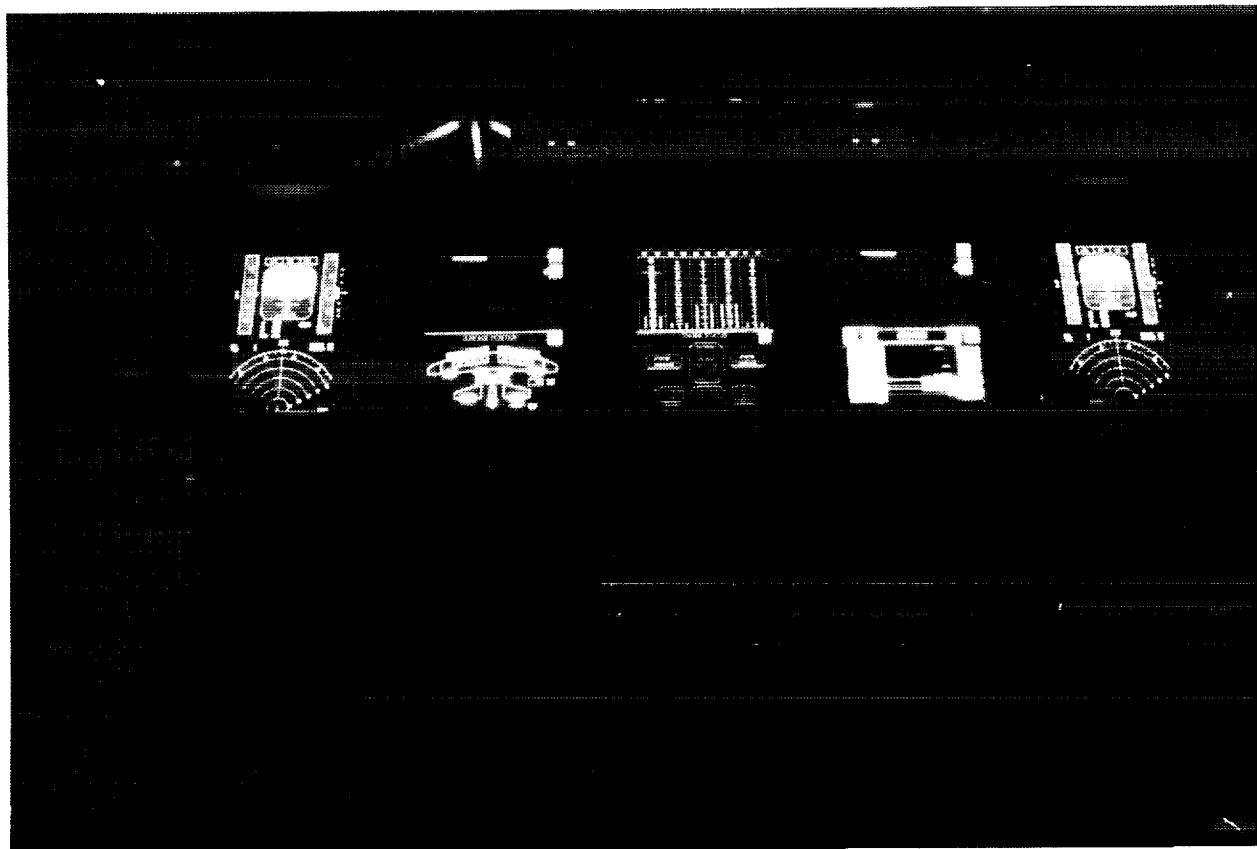


Figure 6. Advanced Concepts Flight Simulator.

and information management systems. Empirical models of human behavior will be developed to predict pilots' ability to manage priorities, strategies, attention, and effort. Research will be performed to demonstrate enhancements in situational awareness and performance using perspective displays, and to demonstrate improved pilot performance in low visibility using sensor fusion. The Man-Machine Interface Design and Analysis System (MIDAS, discussed under Goal 5 Aeronautics) will be used to incorporate pilot models and mission requirements to allow cockpit design and computational evaluation of display and control law strategies on pilot performance.

### **GOAL 3 AERONAUTICS—HIGH PERFORMANCE MILITARY AIRCRAFT**

**Ready technology options for revolutionary new capabilities in future high performance fixed- and rotary-wing aircraft.**

#### **Supersonic Short Takeoff and Vertical Landing Technology**

Short takeoff and vertical landing (STOVL) technology will enhance the performance of advanced supersonic fighter aircraft with the added advantage of vertical flight capability. Supersonic STOVL aircraft offer the potential for a revolutionary increase in the capabilities of advanced fighters, including a solution for maintaining operations from damaged airfields, enhanced operation from aircraft carriers and small ships, and increased supermaneuverability and high angle-of-attack operations using thrust vectoring in flight. STOVL conceptual design studies have resulted in an assessment of promising concepts for future development, a statement of STOVL airframe/propulsion integration design attributes which are required, and a definition of the critical technology risk areas.

The current STOVL program is directed toward reducing the technology risk associated with developing advanced military aircraft. The Directorate emphasis is on aircraft and ground environment design issues (fig. 7) and on flight/propulsion control integration. Recent research results are given in reference 11. A hover test facility is being used to provide for small-scale tests of jet-induced effects in close proximity to the ground and hot-gas ingestion characteristics. This augments the full-scale efforts being conducted in the Outdoor Aerodynamics Research Facility and 40- by 80-Foot and 80- by 120-Foot Wind Tunnels and provides an additional data source for computational fluid dynamics (CFD) validation. Integrated flight propulsion control concepts for approach/landing have been developed and verified in piloted simulations, and will be validated in flight by modifying a YAV-8B Harrier through integrated attitude and thrust vectoring control.

#### **High-Speed Rotorcraft Technology**

Research planned and under way will provide new configurations of advanced high-speed rotorcraft concepts and an initial technology base for future military requirements. Promising configurations being investigated include a high-speed tiltrotors, folding tiltrotors, tilt wings, and stopped rotors (fig. 8). In addition to vertical takeoff and landing capability, possible improvements include a

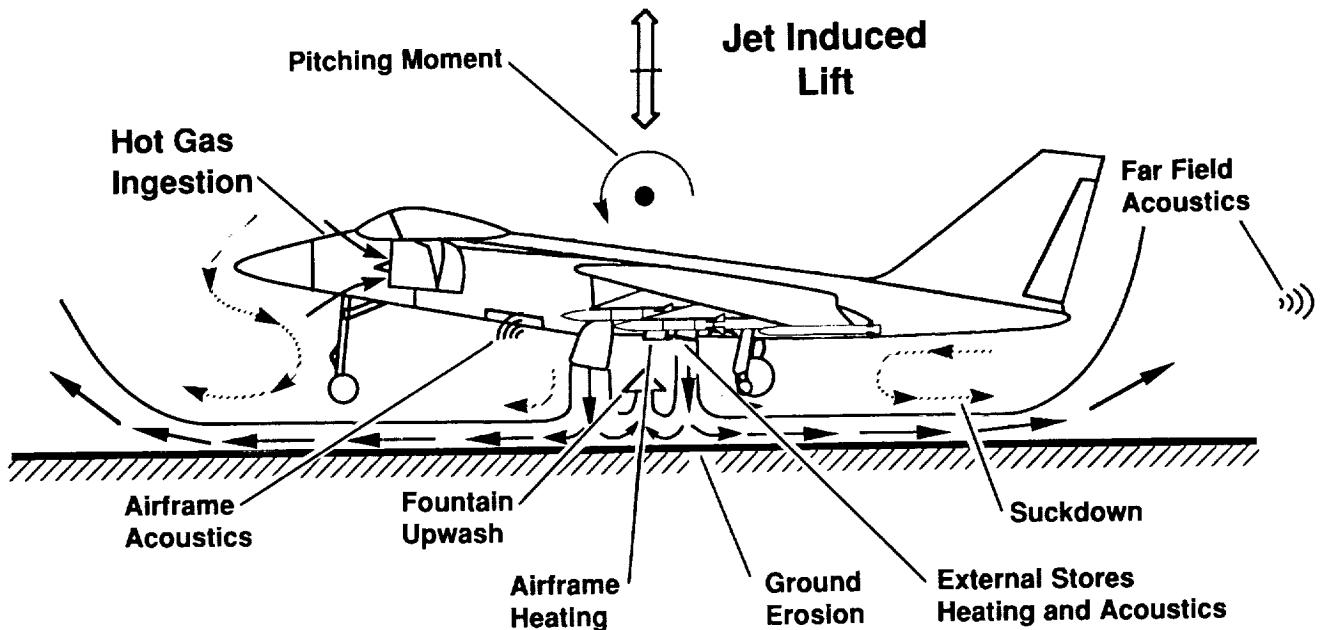


Figure 7. Aircraft and ground environment challenges.

more than 300% increase in productivity (speeds to 500 knots), range, and altitude, with greatly enhanced maneuverability and agility, and quiet operation with fixed-wing vibration levels. These vehicles could enable wider military and civil rotorcraft applications.

The goal of the High-Speed Rotorcraft Program is to identify the technology required to achieve a forward flight speed approaching 450 knots while maintaining helicopter-like hovering capability (ref. 12). The Directorate is performing a wide range of in-house studies to evaluate the technology needs of various concepts for achieving this goal on representative missions (ref. 13). The effect of constraints and the importance of technology advances, on concept weight, performance, and operating cost are being identified.

### Rotorcraft Maneuverability, Agility, and Nap-of-the-Earth Flight

Three rotorcraft programs are directed toward enhancing maneuverability, agility, and Nap-of-the-Earth (NOE) flight for military applications. These are a rotorcraft aeromechanics program, the Superaugmented Control for Agile Maneuvering Performance (SCAMP) Program and the Automated NOE Program. All these programs are cooperative with the Army.

The critical element in rotorcraft performance, agility, and maneuverability is the steady and unsteady airloads experienced by the rotor system(s). A major thrust of the Ames rotorcraft program is to develop and validate the prediction methods that will provide the basis for new design tools. A multifaceted rotor airloads program is under way in the Directorate. This program is providing an extensive data base for modern four-bladed rotors fulfilling the industry need. This involves small-scale and large-scale wind tunnel testing and flight testing of specially instrumented rotors. This program is complemented by specialized testing for active controls, noise reduction, and vibration

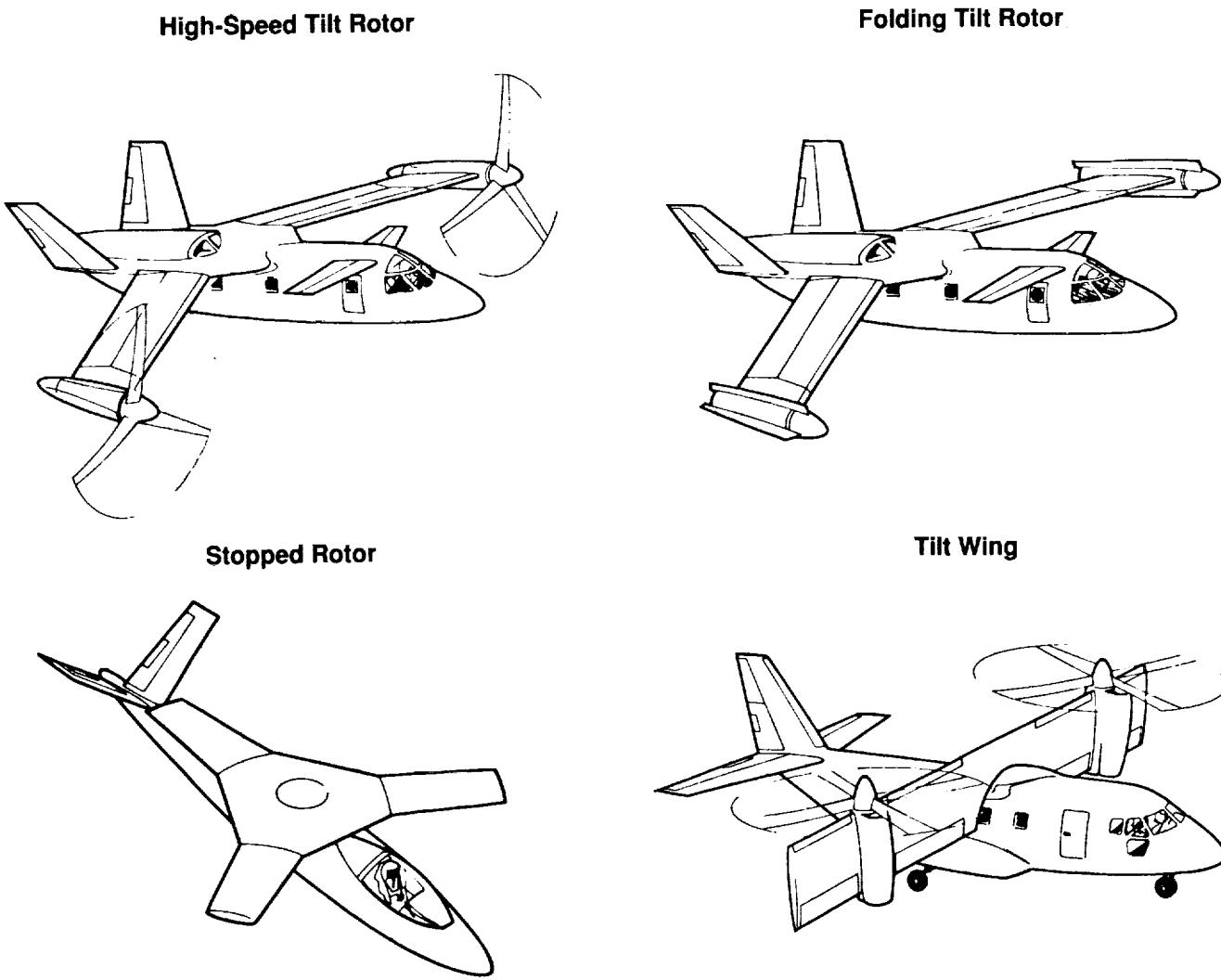


Figure 8. High-speed rotorcraft concepts.

reduction. Parallel development of advanced analytical tools is also under way for correlation and validation activities with these experimental data.

Much of the airloads research is being focused on a specially instrumented UH-60 rotor system. Small-scale testing under a joint Army/NASA program of the UH-60 rotor system has already been completed. A major effort is under way to prepare the large-scale wind tunnel and the flight capability to meet the extensive testing requirements for the UH-60 rotor airloads program (ref. 14). A UH-60 Black Hawk helicopter is being prepared, along with a high-rate data acquisition and processing system for the flight portion of the program. A large rotor test apparatus is being developed for testing this rotor and other full-scale rotors in the National Full-Scale Aerodynamics Complex (NFAC).

A critical technology is the use of closed-loop controls to modify rotor loads and blade dynamics, because of rotor system limitations of rotorcraft in maneuvering flight. Due to the unique

capability to conduct full-scale rotor system investigations in the NFAC, a major research thrust is the evaluation and demonstration of various control methodologies for expanding the rotor flight envelope in maneuvers. Through the use of rotating system sensors (strain gages, accelerometers, and pressure gages), wind tunnel programs will investigate the use of active blade pitch control to modify blade dynamic states for loads reduction, stability augmentation, and flying qualities improvements.

A new approach that goes beyond conventional swashplate implementation of controls is individual blade control (IBC) using actuators in the rotating system. A series of tests is planned where the pitch links will be replaced by IBC actuators. Using a BO-105 rotor system, the program will specifically address the advantages of nonharmonic and multiple-harmonic blade pitch control. A new technology effort has also begun in the use of piezoelectric actuators distributed within the blade structure to enable control of elastic blade deflections for optimal maneuvering capability.

The previous aeromechanics programs are complemented by the SCAMP Program which has the objective of improving rotorcraft agility and maneuverability. The SCAMP Program has the following goals: (1) providing concepts, methodologies, and criteria for integrated control design for rotorcraft; (2) using these methodologies to provide significant increases in rotorcraft agility and maneuverability; and (3) validating these improvements in flight through the development of a rotorcraft airborne simulator. Research will concentrate on developing methods to integrate stability/control augmentation, rotor state feedback, flight/propulsion control, and higher harmonic control techniques. The UH-60 has been selected as the airborne simulator with the capabilities of both validating ground simulation flying-qualities results, and examining these integrated control technology concepts. It is planned to retrofit the UH-60 with a programmable fly-by-wire control system to perform the required flight investigations and validations.

The Automated NOE Program is aimed at developing technology leading to enhanced low-altitude/NOE flight path management and control through computer aiding (ref. 15). The key problem to overcome is the detection and avoidance of unknown obstacles. The current emphasis in obstacle-detection research is to develop the capability to use image-processing techniques on passive sensors to detect trees, buildings, and other objects. The obstacle-avoidance research is focused on developing guidance aids for the pilot, using both algorithms and heuristic methods. The integration of the obstacle-detection and obstacle-avoidance methods will be studied on a workstation-based, real-time simulation in the laboratory. Upon completion of the testing in a workstation environment, concepts will be tested as part of a piloted evaluation of computer-aided NOE flight.

### **High Angle-of-Attack Aerodynamics**

The control and maneuver of fighter aircraft at angles of attack well beyond stall are rapidly becoming important capabilities which can determine survivability and combat effectiveness. A full-scale F/A-18 airframe will be tested in the 80- by 120-Foot Wind Tunnel at angles of attack ranging up to nearly  $60^{\circ}$  to evaluate forebody flow control concepts. Pneumatic forebody flow control using blowing slots and discrete jets will be evaluated in preparation for flight testing on the High Angle-of-Attack Research Vehicle being flown at the Ames Dryden Flight Research Facility. The comprehensive data set from the wind tunnel tests will include aircraft forces and moments, time-average

surface pressures, surface and flow-field flow visualization, and the structural response and unsteady surface pressures on the vertical tail surfaces. These detailed measurements will be used to determine the effects of scale and Reynolds number on high-alpha test results and to develop and validate computational analysis and design methods. The experimental program and the CFD research will emphasize the understanding, prediction, and control of the highly energetic vortex flow fields, vortex bursting, and tail buffet phenomena.

## **GOAL 4 AERONAUTICS—HYPERSONIC/TRANSATMOSPHERIC VEHICLES**

**Develop critical technologies to support ground and flight demonstration of the X-30 National Aerospace Plane (NASP) and the development of future hypersonic vehicles.**

### **Conceptual Design**

The Aerospace Systems Directorate has been a key contributor to the NASP Program by providing conceptual design study results to both the Joint Program Office (JPO) and the airframe contractors. The design synthesis program that has been developed, called HAVOC, uses key hypersonic vehicle design parameters to estimate aircraft sizing and economics. Studies for the JPO have been used to estimate the effect of changing mission requirements, to validate contractor design decisions and performance analyses, and to evaluate the risk in contractor technical approaches through parametric sensitivity analyses. Also, design methods developed within the Directorate, such as an arbitrary geometry structural analysis, are being used by the NASP contractor team.

The NASA Generic Hypersonic Program is involved with hypersonic research that does not include the NASP goal of X-30 development. Using the same design synthesis methods developed for NASP, the Directorate performs a wide range of studies including different concepts of aircraft geometry and different mission requirements/constraints. For example, recent evaluations have focused on the advantages/disadvantages of wave rider configurations compared to current NASP designs for single-stage-to-orbit vehicles (ref. 16). An oblique flying wing and various forms of all-rocket designs have also been investigated. Studies to follow will include hypersonic cruise vehicles and analysis of single-stage versus two-stage to orbit approaches for rocket-powered vehicles. Innovative concepts for launch vehicles will also be evaluated for NASA's Advanced Launch System Program.

### **Testing of Configurations**

The Directorate will support the NASP Program in areas of low-speed aerodynamics, aero-propulsion integration, human factors, and control and guidance research. Aerodynamic studies and wind tunnel tests will be performed to assess the performance, stability, and control characteristics at takeoff, approach, and landing. Control, guidance, and human factors will be investigated using flight simulators to establish requirements for the NASP.

## **GOAL 5 AERONAUTICS—CRITICAL DISCIPLINES**

**Pioneer the development of innovative concepts, and provide the physical understanding and the theoretical, experimental, and computational tools required for the efficient design and operation of advanced aerospace systems.**

### **Vision Science and Technology**

Flight operations in inclement weather, such as rain and fog, continues to be a concern in general and commercial aviation due to low visibility. Although poor visibility often results in reduced flight operations, mishaps still occur on the ground when aircraft are on the wrong runways or taxiways. The final safety check, the pilot's visual inspection, is denied during low-visibility conditions. Research is under way to augment pilots' vision in low-visibility conditions.

A computational model of human vision has been developed using an image-processing technique called Multi-resolution Pyramid Coding. Methods are being developed to fuse images gathered in the visible spectrum or images rendered from computer data bases, such as flight simulator data bases, with real-time imagery gathered by a millimeter band camera system. Because the atmospheric extinction coefficient in the gigahertz range (i.e., millimeter bands) is small, these wavelengths can be used to "see through fog." Multi-resolution Pyramid Coding simplifies the problem of fusing these images with imagery from the visible band. This will potentially permit pilots to readily interpret the fused imagery to detect runway intrusions from aircraft lost in fog and other threats that may not be known to the ground and air traffic controllers.

### **Human-Machine Interface Design Tools**

Piloting difficulties in advanced vehicles can be reduced by incorporating human factors computer-aided engineering early in the design process. The Army-NASA Aircrew/Aircraft Integration (A<sup>3</sup>I) Program is a joint Army and NASA exploratory development effort to advance the capabilities and use of computational representations of human performance and behavior in the design, synthesis, and analysis of manned systems. The program's goal is to conduct and integrate the applied research necessary to develop an engineering environment containing the tools and models needed to assist crew station developers in the conceptual design phase. A major product of this research is a prototype human factors/computer-aided engineering system called Man-Machine Integration Design and Analysis System (MIDAS). Recent developments to MIDAS are given in reference 17.

The MIDAS system provides design engineers/analysts with interactive symbolic, analytic, and graphical components which permit the early integration and visualization of human engineering principles (fig. 9). MIDAS is a model and principle-based human factors methodology to aid

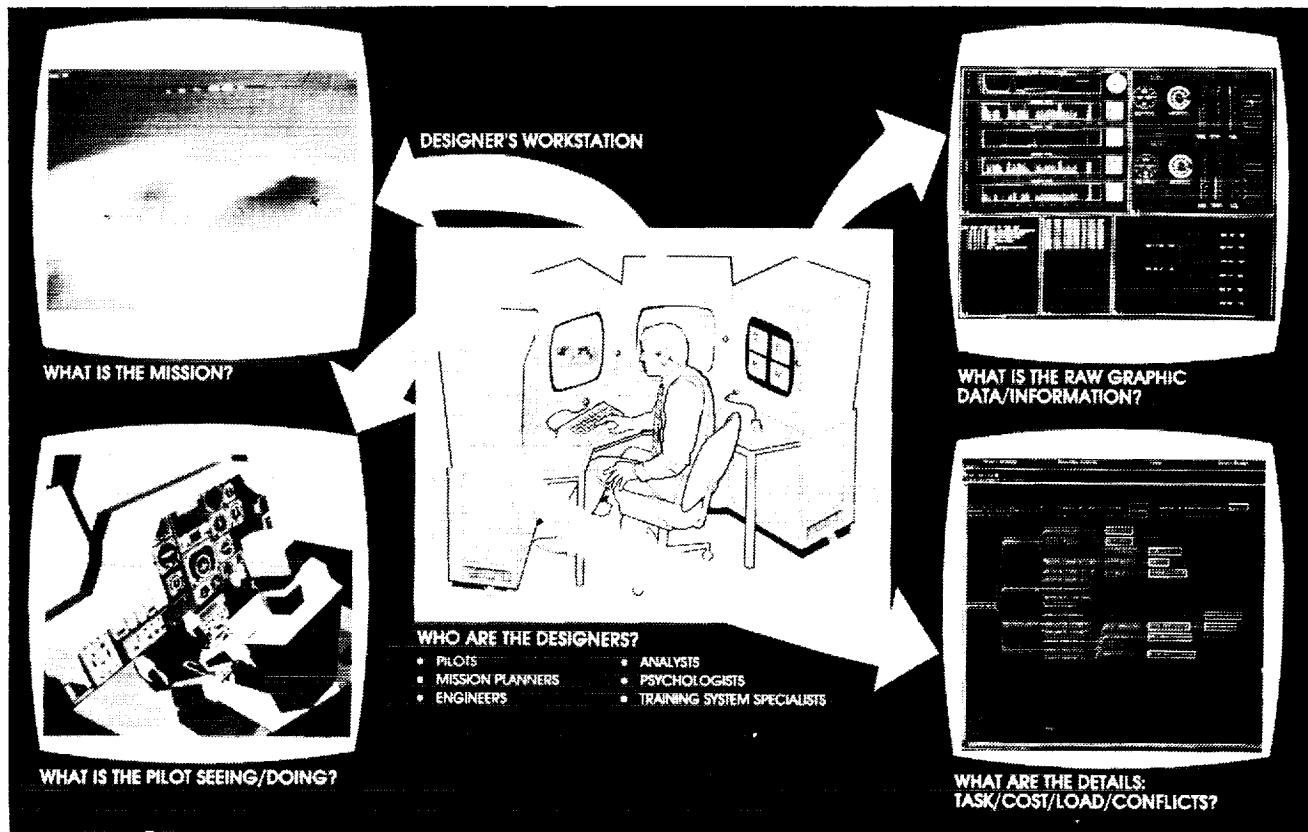


Figure 9. Man-Machine Integration Design, and Analysis System.

designers in the conceptual phase of crew station and training system development. MIDAS contains tools to describe the operating environment, equipment, and mission of manned systems, with models of human performance/behavior used in static and dynamic modes to evaluate aspects of the crew station design and operator task performance. The results are presented graphically and visually to the design engineers.

### Parallel Processing

Parallel processing research for aeronautical research and engineering applications has developed tools for decomposing existing computer programs to analyze architectures for simultaneous execution of code components. This technique was applied to CFD as well as to the multiple instruction data codes in computational electromagnetics, real-time simulation, and, in the near future, to aircraft design synthesis. Parallel processing can significantly decrease computer run time and improve overall system performance. It enables object-oriented computations and concurrent engineering where detailed analytical codes from many disciplines can be interfaced, and thereby reduces design time and costs.

Application of parallel processing to real-time rotorcraft simulation, where accurate models are much more complex than their fixed-wing counterparts, exhibited dramatic results. Improved fidelity

was demonstrated by replacing the rotor map model with a more accurate blade-element representation running on a parallel processor computer interfaced with a UH-60 Black Hawk training simulator (ref. 18). Similarly, a more powerful parallel processor was used with the Crew Station Research and Development Facility to replace the vehicle mathematical model with one that calculated rotor aeroelasticity and structural dynamics in real time (ref. 19).

## GOAL 6 AERONAUTICS—NATIONAL FACILITIES

**Develop, maintain, and operate critical national facilities for aeronautical research and for support of industry, Department of Defense (DOD), and other NASA programs.**

An important factor in any research and development organization is the quality of its facilities. A premier research capability has been achieved at Ames by developing unique facilities and by maintaining and improving them. The Directorate's present major facilities include the National Full-Scale Aerodynamics Complex, Flight Simulation Complex, and the Man Vehicle Systems Research Facility. Research aircraft are developed and used for proof-of-concept investigations and as flying research facilities.

### National Full-Scale Aerodynamics Complex

The National Full-Scale Aerodynamics Complex (NFAC) provides the United States with the capability of performing wind tunnel testing on large-scale and full-scale aerospace vehicles and components and of conducting low-speed aerodynamic research in fundamental flow phenomena. This complex consists of three elements (fig. 10): the 40- by 80-Foot Wind Tunnel, the 80- by 120-Foot Wind Tunnel, and the Outdoor Aerodynamic Research Facility (OARF).

The 40- by 80-Foot Wind Tunnel is a closed-circuit tunnel with a test section 40 ft high by 80 ft wide and a maximum airspeed of approximately 300 knots. It was built originally to test and evaluate takeoff and landing characteristics of full-scale aircraft. It has been used for testing fighter aircraft, lifting-body configurations, large-scale supersonic transport and Space Shuttle models, V/STOL and STOL aircraft and models, advanced rotor systems and rotorcraft, jet-engine noise-suppression systems, and a variety of other items such as parachutes and radar installations.

The 80- by 120-Foot Wind Tunnel is an open-circuit tunnel with a test section 80 ft high by 120 ft wide and a maximum airspeed of approximately 100 knots. Because of its size, the 80- by 120-Foot Wind Tunnel can be used to investigate full-scale aircraft and rotor systems at very low forward flight speeds in a ground-based facility with minimal wind tunnel wall effects. Its size permits the evaluation of very large models or even actual aircraft as large as mid-range jet transports.

Both tunnel test sections are lined with sound-absorption material to allow acoustic data on test articles to be gathered. Acoustic improvements to NFAC have been proposed which would include variable rpm fan control, tunnel corner treatment, and new, more effective 40- by 80-foot test section lining.

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Figure 10. National Full-Scale Aerodynamics Complex.

The OARF is used to obtain a wide range of ground-based hover and acoustic data on full-scale or small-scale rotorcraft and V/STOL aircraft and propulsion systems. It is also used to check out test articles before they are installed in the wind tunnels.

### Flight Simulation Complex

Flight simulators create an authentic aircraft environment by generating the appropriate physical cues that provide the sensations of flight. The simulation facilities being used at Ames include the Vertical Motion Simulator (VMS), the Interchangeable Cab (ICAB) Development Station, and computer and visual system laboratories. The simulation complex is used to investigate the flight dynamics, handling qualities, and performance of advanced vehicles, and new flight control and display concepts. It is also used to develop new test techniques for using flight simulation and to define the requirements and develop technology for training simulators.

The 6-degree-of-freedom VMS, with its unique motion capability ( $\pm 30$  ft vertical displacement,  $\pm 20$  ft lateral displacement,  $\pm 4$  ft longitudinal displacement) is one of the world's largest motion-based simulators (fig. 11). It is used to simulate a complete spectrum of flight vehicles, including the

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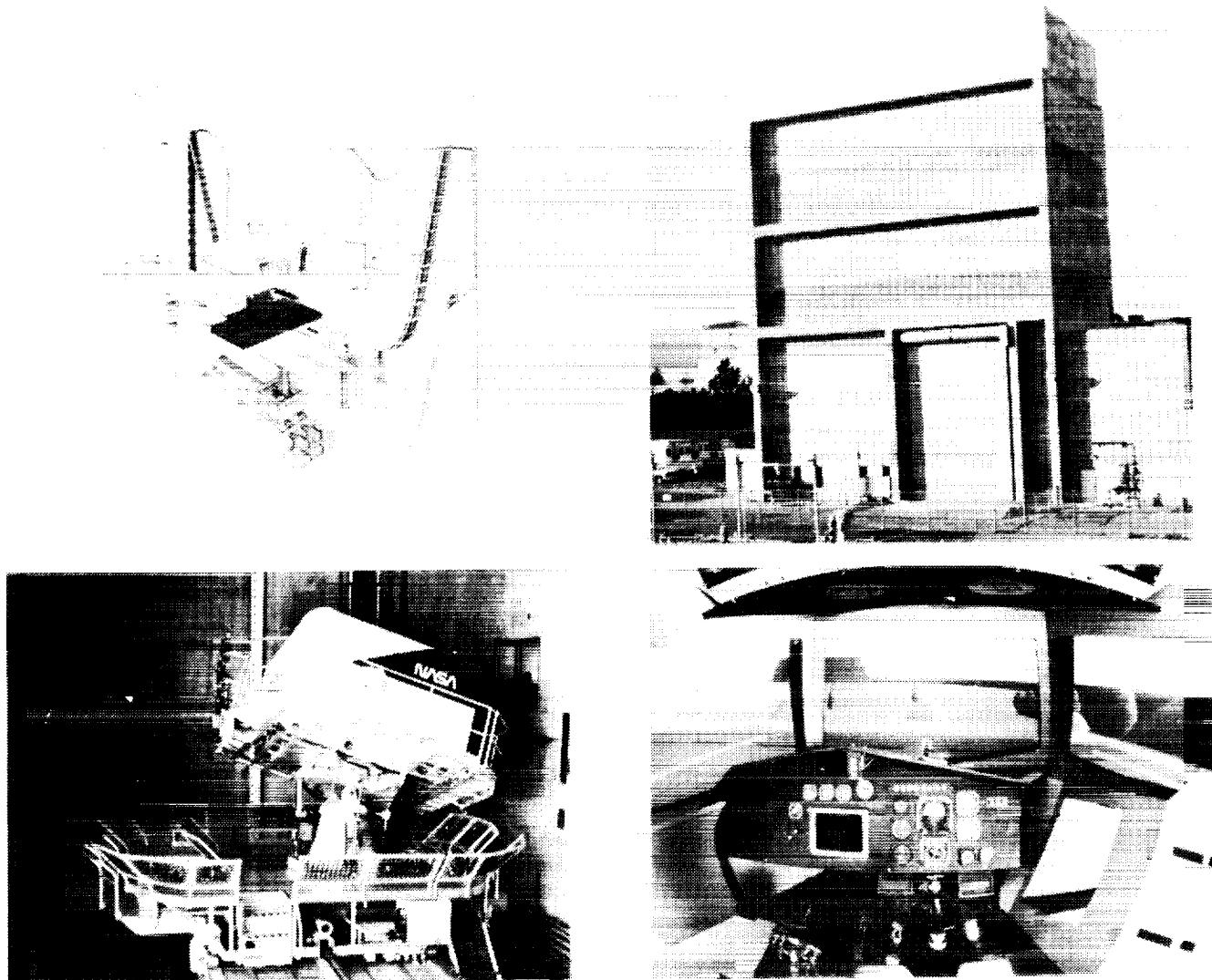


Figure 11. Vertical Motion Simulator.

Space Shuttle, civil and military transports, fighters, and rotary-wing aircraft. It has been used extensively for helicopters, tiltrotor aircraft, and other aircraft that take off and land vertically or on short runways. The VMS has been used extensively for astronaut evaluation and training and for supporting shuttle landing system engineering studies.

The VMS is controlled by large digital computers that are programmed to represent the aircraft and the external environment. The computer system calculates the correct aircraft response to control inputs in real time and provides appropriate instrument readings and accelerations through the motion system to the cockpit. The computer-generated visual-display system updates the pilot's view through the windshield with visual scenes that range from landscapes and runways to an aircraft carrier at sea.

The ICAB Development Station is used both to configure and check out a variety of interchangeable simulator cabs prior to placement on the VMS, and to conduct fixed-base simulation investigations. Increased VMS operational efficiency results from this off-line modification and its check-out capability.

### **Man-Vehicle Systems Research Facility**

The Man-Vehicle Systems Research Facility (MVSRF) represents a unique national facility designed to study human factors in aviation (fig. 12). The MVSRF has full mission capability with an air traffic control simulator, where the flight crew can perform a full range of flight missions in an operational context. The MVSRF allows scientists to study the factors that contribute to human errors. It also allows the study of the effects of automation, advanced instrumentation, and other factors such as crew interaction and fatigue on human performance in aircraft. Scientists and researchers analyze performance characteristics of flight crews, formulate principles and design criteria for future aviation environments, evaluate new subsystem concepts in contemporary flight and air traffic control, and develop new training and simulation techniques required by the continued technical evolution of flight systems. Examples of specific experiments include the evaluation of electronic checklists, automation tools for air traffic control, traffic alert and collision avoidance systems, and complex microwave landing system (MLS) procedures in multi-airport environments. Many such investigations are performed jointly with the FAA or with U.S. industry.

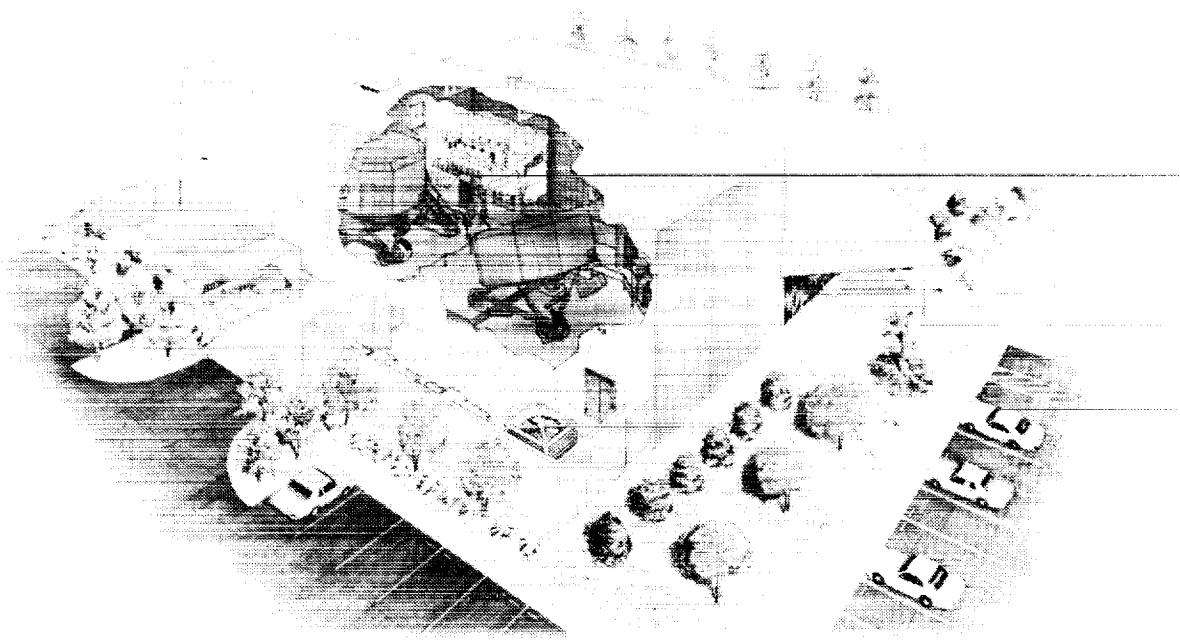


Figure 12. Man-Vehicle Systems Research Facility.

The MVSRF includes an ATC system simulator and two flight simulators—a current high-fidelity aircraft simulator (Boeing 727) and an Advanced-Concepts Flight Simulator, used as a test bed for future cockpit technology. Both flight simulators have motion and are capable of full-mission simulation. Computer-generated visual displays provide out-the-window cues to each cockpit. The ATC system simulator provides a realistic ATC environment, allowing the study of air-ground communications as they affect crew performance. To maintain the MVSRF's ability to focus on current and anticipated human factors issues pertaining to the operation in the National Aviation System, a currently operational transport aircraft "glass cockpit" simulator is being planned as a replacement for the B727 cockpit.

### **Flight Research Aircraft**

The final step in the aerospace research and development process is flight research, which provides unique data to validate ground-based research results. The Aerospace Systems Directorate develops and uses research aircraft to (1) investigate fundamental rotorcraft aeromechanics and noise, powered-lift aerodynamics, advanced control and guidance concepts, and human factors issues; (2) define handling qualities criteria; and (3) conduct proof-of-concept evaluations of new rotary-wing and powered-lift research aircraft. Rotary-wing aircraft test beds include UH-60 rotor airloads research aircraft (fig. 13), the Tiltrotor Research Aircraft (XV-15), UH-60 controls and guidance research aircraft, and the AH-1S equipped with a pilot night-vision system. Powered-lift research aircraft include the Quiet Short-Haul Research Aircraft (QSRA) and the V/STOL Research Aircraft (YAV-8B) (fig. 14). Operation of the research aircraft is the responsibility of the Ames Research Aircraft Operations Division.

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Figure 13. UH-60 aircraft.

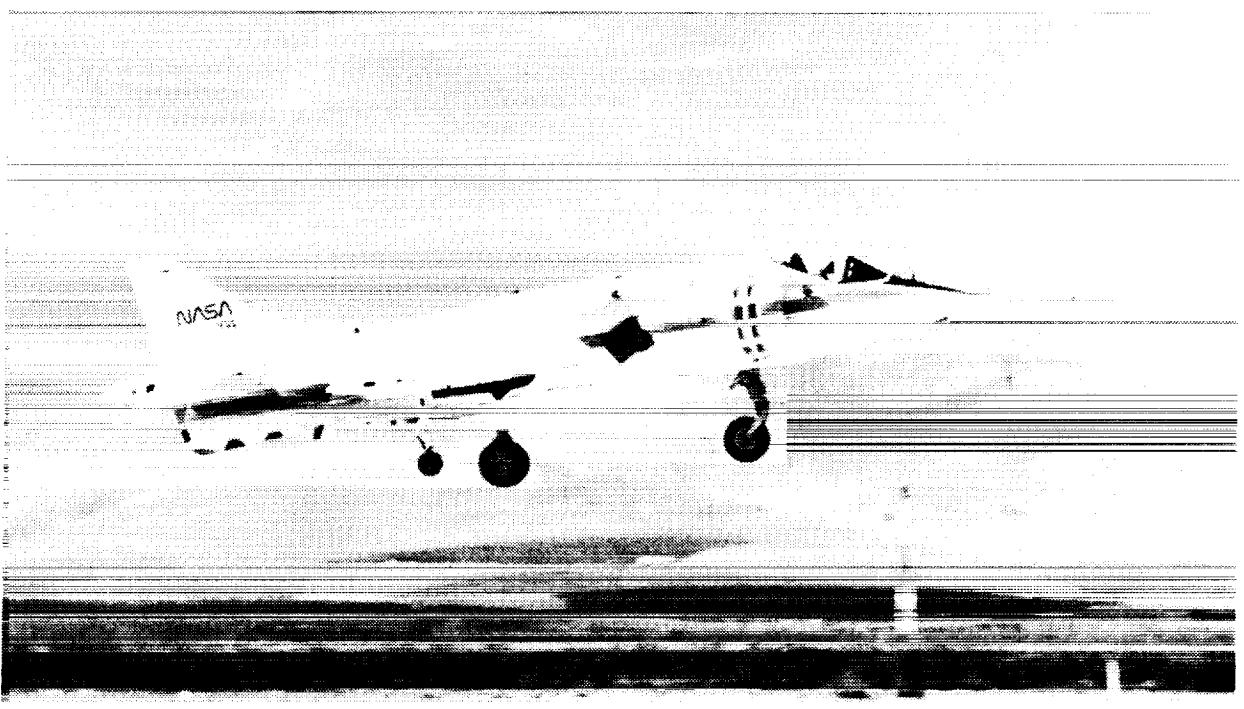


Figure 14. V/STOL research aircraft (YAV-8B).

## **GOAL 1 SPACE—EXPLORATION**

**Develop and demonstrate key technologies to enable the Nation's space exploration objectives. This includes technologies to increase reliability and reduce risk, and to reduce the cost and enhance capabilities for human and robotic exploration missions to the Moon and Mars, which will lead to a human expedition to Mars before 2019.**

### **Automation Sciences Research Facility/Human Performance Research Laboratory**

The Automation Sciences Research Facility (ASRF), is designed to address research and development of machine intelligent systems that may be used to assist humans or as controllers for automated devices (fig. 15). Intelligent systems use high performance computers in autonomous systems that can adapt to new situations and pursue high-level, goal-oriented situations. The ASRF includes individual research laboratories for the investigation and evaluation of machine learning; planning and scheduling; high performance computer systems capable of integrating numeric/symbolic

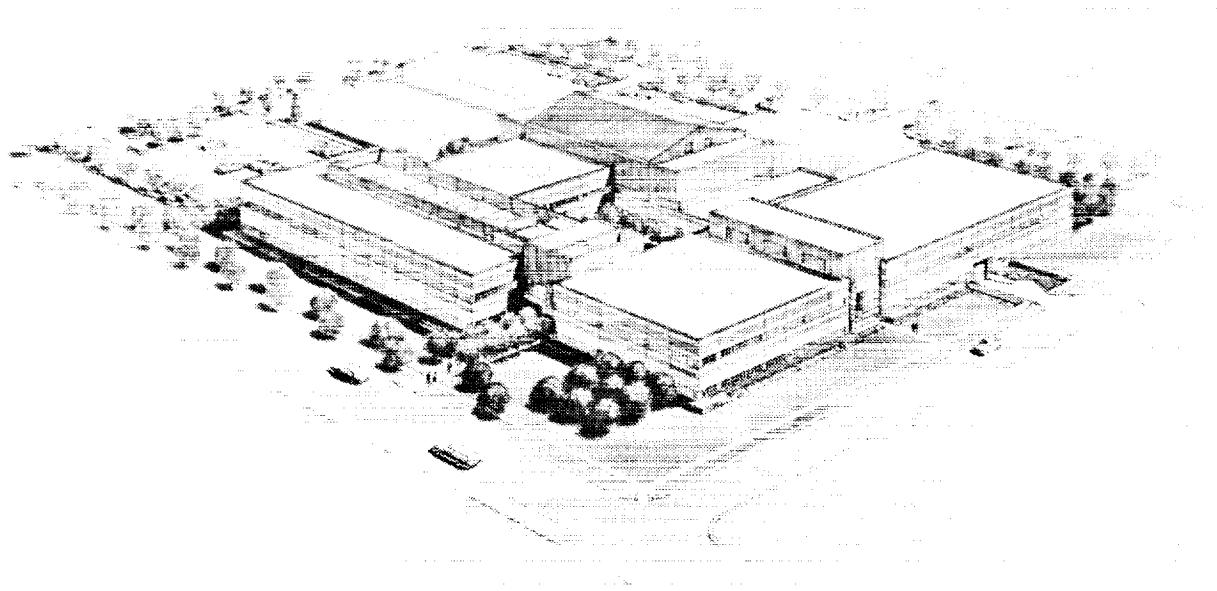


Figure 15. Automation Sciences and Human Performance Complex.

processing; photonic processors for control and execution of image-oriented processes; neural networks; intelligent mechanisms; and Ames/DARPA National Testbed for Advanced Computer Architectures.

The Human Performance Research Laboratory (HPRL) collocated with the ASRF, supports a variety of basic and applied studies of human performance and the interaction of humans with complex machines and machine intelligent systems designed to improve the safety and reliability of aerospace missions. Individual laboratories support cognitive, perceptual, and social scientists and engineers working on advanced aeronautical and space problems. A 12,000-ft<sup>2</sup> high-bay area shared with the ASRF is intended to house moderate to high-fidelity test beds for the development, validation, and verification of human-intelligent systems technology.

### **Exploration Human Support Technology**

As we begin the detailed planning for the next phase of human exploration of space, it is clear that human capabilities and limitations during long-duration missions must be considered carefully in the design of the missions and of all the systems that the astronauts will be expected to operate and maintain (ref. 20). The most powerful approaches to human exploration of space will integrate humans with machines to accomplish more than either can do alone. Computer-aided extensions of human experts can enhance human effectiveness and efficiency in inspection, assembly, operation, maintenance, and repair of the complex space systems, and in performing the exploration tasks of the missions. Systems that integrate automation and robotics with humans permeate the arenas of vehicle maneuvering, vehicle servicing in space, in-space and surface assembly and construction, planetary rovers, surface operations, extravehicular activity and exploration, sample acquisition and analysis, and scientific probes and penetrators.

The human-machine systems for the space exploration missions must be designed according to a philosophy of human-centered automation, because the effective authority and responsibility for mission success will rest with the crew. The crew will have control of machine resources; that is, the crew will have ways to instruct and direct machine agents in support of crew-determined goals. Automated systems will provide support for the crew's performance of critical tasks. The systems will be designed to enable maximum flexibility in the crew's selection between automation and manual control in the performance of a given task. The crew will supervise lower-order automated systems and will therefore need support for high-level situation assessment including what the systems are doing, why they are doing it, and what they will do next. Implications of human factors issues cut across the designs of all the key technologies and missions of space exploration, whether the humans are located on Earth, in space, or on a planetary surface.

Humans in space will require habitats that are compatible with their physical, social, and psychological requirements. However, a great deal of research is needed to understand how to design these systems and their interfaces with assurance of effective, safe, and reliable human interaction. Research is under way in the areas of crew communication and team performance for various operational settings (ref. 21); understanding and development of intelligent-aiding systems; and monitoring and control of habitat systems. Researchers are also studying environments analogous to

long-duration space flights such as Antarctic research stations (ref. 22) and undersea laboratories (fig. 16) to better understand how humans respond to isolated and confined settings.

Current habitability research focuses on developing behaviorally based architectural and interior design guidelines. This work will eventually expand to test the stress countermeasure value of various interior design treatments. Guidelines are being developed to assist in interior design and decor by assessing human-performance requirements and applying principles of environmental psychology. These guidelines will assist planners in ensuring a comfortable and nonmonotonous environment. The guidelines will also help scientists to select appropriate graphics, color, and light schemes. Results of long-range human habitability research will be applied to the planning and design of future habitats and vehicles that will enable permanent residency in space and on other planetary surfaces.

Sending a human to the surface of another planet cannot be accomplished without a great deal of prior remote or robotic exploration of the potential site. A research program in the areas of virtual planetary exploration (refs. 23 and 24) allows the astronaut to "virtually" explore the planetary

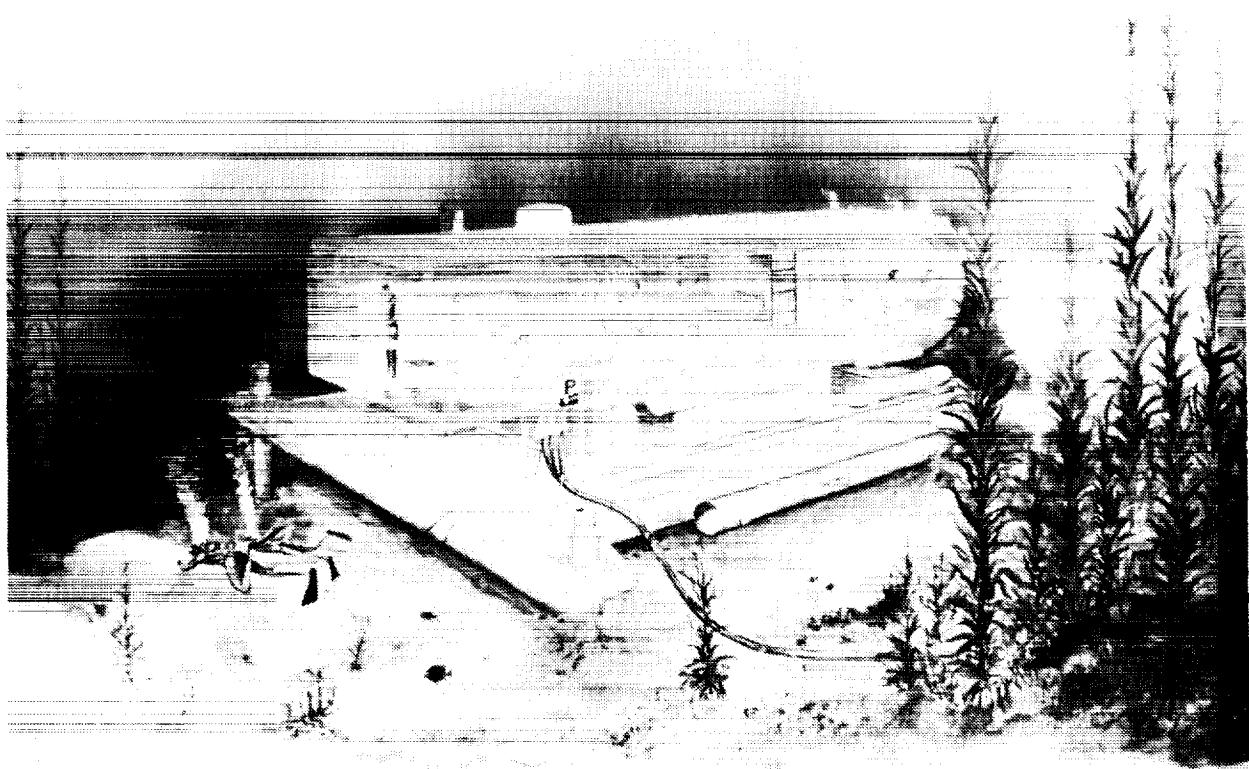


Figure 16. Undersea scientific habitat analogs.

surface without really being there (fig. 17). The objective of the Visualization for Planetary Exploration Program is to conduct research and development of crew interfaces for in-space, terrain exploration systems. The approach is to (1) review previous operational experiences, mission constraints and opportunities, and the state of the art in exploration technology; (2) investigate user behaviors and requirements; and (3) enlist interdisciplinary expertise to develop, implement, demonstrate, and evaluate advanced interfaces for crew interaction with data collection systems.

Field studies have been conducted to understand operations central to planetary-surface exploration. In addition, a planetary terrain visualization test bed is under development to support focused user-interface research. A computer system has been developed which provides dynamic interaction with planetary terrain data (currently, Mars and Earth, but easily applicable to Venus, Earth's moon, or other planetary bodies). A Virtual Workstation is being developed to enable greatly improved situation awareness in complex spatial environments; to enable high-fidelity telepresence for control of telerobots; to simulate workstations, cockpits, and module interiors; and to enable improved scientific-visualization interfaces for exploration of planetary surface data.

Maneuvers in space have traditionally required advance planning using extensive computation of orbital mechanics on large, ground-based computer systems. A project called NAVIE is being developed to allow on-board solutions to these nonlinear, nonintuitive problems without requiring lengthy

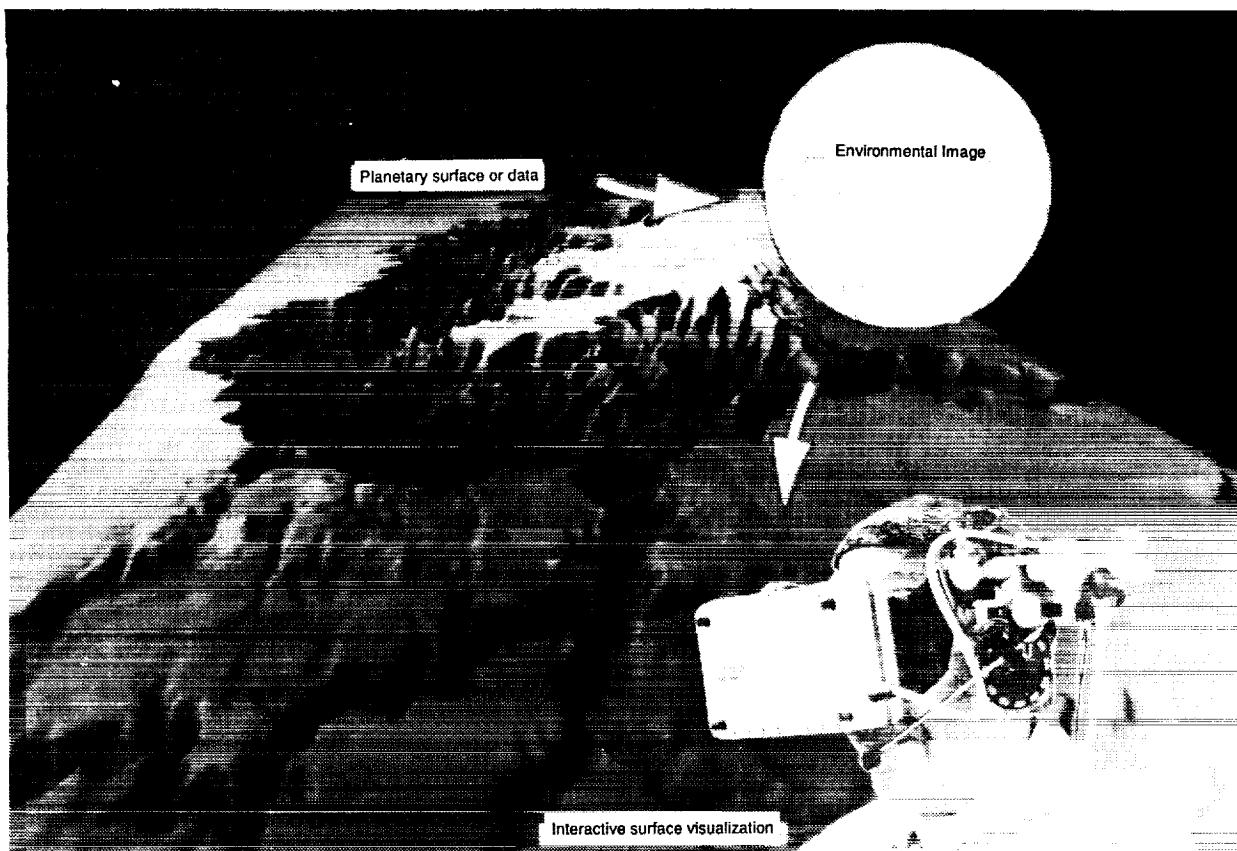


Figure 17. Visualization for planetary exploration.

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computer searches (refs. 25 and 26). The goal of this project is to develop, demonstrate, and evaluate advanced interface concepts such as image-communication systems and visually oriented planning-and-control systems. A display is being developed which uses inverse kinematics and a human operator's intuitions in 3-D perspective to find optimal solutions to the problem at hand. Experiments have shown that interactive optimization (i.e., a human and a machine cooperating to solve an optimization problem) using this display works as well as the lengthy computer searches.

### Cognitive and Perceptual Models

Even in the absence of detailed mission scenarios, it is clear that the future space-exploration missions will involve highly complex systems, difficult and varied human performance tasks, and high levels of advanced automation. A small crew will have to manage a variety of potential problems with complicated systems without the kind of close coordination with mission control on Earth that is now the norm. Mission success depends, in large part, upon the effective design of the crew's workstations. Human-centered design ensures that information is presented clearly, and that crew intentions are effectively communicated to the machine.

Human-centered designs require a basic understanding of human capabilities and limitations in the physical, cognitive, perceptual, and behavioral domains. Guidelines based on human performance models will enable the engineer to plan a well-designed working and living environment. Efficient and effective methods for modeling human performance under varying gravity conditions are essential to support the technology developments for future missions. Computational models must be extended from their current state to incorporate the possible effects of long-duration altered gravity on perception and on the integration of sensory information.

Research is under way in developing validated human performance computational models to provide guidelines for design of systems to ensure effective, safe, and reliable human operation and system maintenance. Cognitive and perceptual models will be compared with human behavior. Successful models will be used to establish guidelines for the design of system architectures and displays, and for the formulation of mission plans that ease human memory load.

The research on cognitive and perceptual models uses the Man-Machine Integration Design and Analysis System (MIDAS) discussed under Goal 5 Aeronautics. The perceptual and cognitive models in MIDAS will be modified to provide a tool to assist designers in understanding how an astronaut will use sensory cues from displays or the natural environment to perform the required tasks. Our objective is to use these models to predict the actions of crew members in various situations, and to use this predictive capability to choose between alternative design options during an early stage of conceptual design.

The Resource Constraint Model developed in support of MIDAS is based on an assumed architecture of the human information processing system. This model of perceptual attention is being incorporated in An Integrated Architecture for Learning (called ICARUS), an existing computational model that accounts for phenomena in human concept learning and human problem solving (ref. 27). To make this theory of the human information processing architecture more accurate, the architecture will include a model of short-term memory limitations, their effect on problem solving, and the

manner in which humans overcome such limits with experience. In addition, tools are being developed for easily implementing models of specific domain knowledge (e.g., of display layout) and strategies (e.g., particular mission plans).

### **A Virtual Interactive Environment for On-Board Training**

Training requirements for the long-duration, manned, space missions will differ from those for short-duration low-Earth-orbit missions and even from those for Lunar-base missions. The autonomy and the sheer length of time of total isolation from Earth preclude the possibility of full-mission simulations and force partial mission training focused on critical activities. Crew training and skill maintenance require special attention in long-duration missions. There must be greater emphasis on enroute training, not only to maintain skills, but to acquire new ones because of limitations on the Earth-bound training.

For missions when a year might elapse between launch and landing, landing procedures must be practiced during the mission. In addition, during a long mission, skill mix requirements may vary. The same astronaut may be called on to be, for example, an astronomer enroute to Mars, a geologist on Mars, and an analytical chemist on the return voyage. Training and refresher courses in the various duties required in different phases of the mission must be available enroute. Astronaut-training activities must be extended and enhanced for long-range training, astronaut self-training, and new concepts developed for mission support.

Advances in the understanding of knowledge representation, human learning, training technology, and artificial intelligence have made possible the development and deployment of Intelligent Computer-Aided Training (ICAT) systems that provide a promising approach to meeting the special requirements of long-duration manned spaceflight. The ICAT concept can be further enhanced by integrating intelligent training with the Virtual Interactive Environment Workstation (VIEWS) that has been developed into a "personal simulation" capability.

Research is directed at studying the effect of the use of advanced visualization interfaces on improving training. This activity is a mission-oriented extension of the Directorate research in spatial information transfer which has already produced innovative perspective formats for the Cockpit Display of Traffic Information program; the Virtual Visual Environment Display (VIVED), an advanced helmet-mounted display; the VIEWS, which adds data gloves and 3-D sound to VIVED; and the NAVIE display for conducting orbital rendezvous maneuvers. It will also be based on our current work addressing advanced interaction media and concepts of computer-integrated documentation.

### **Exploration Information Systems and Automation**

The design of advanced automated and robotic systems with consideration of human-operator interaction is a new field of human factors because meaningful nonhuman "intelligent" systems have only recently become available (ref. 28). Control of autonomous and semi-autonomous telerobotic devices and vehicles requires an interface configuration that allows variable modes of operator

interaction. These range from high-level supervisory control of multiple independent systems to highly interactive kinesthetic coupling between operator and remote systems. Many factors affect the ease, precision, and reliability with which a human can control a remote agent including, for example, the fidelity of the sensory feedback systems which may include visual information from several different perspectives.

Current research is directed at establishing the human-machine requirements for advanced automated and robotic systems. An appropriate interface for supervisory control modes will provide the operator with multiple viewpoints of the remote task environment in a multi-modal display format. The format can be easily reconfigured according to changing task priorities. The Directorate is exploring the value of using a virtual environment to assist the human operator in situation recognition, and in establishing procedures for telerobotic operations.

For remote operations that cannot be performed autonomously, it must be possible for the operator to switch quickly to interactive control. In this telepresence mode, the operator must receive a sufficient quantity and quality of sensory feedback to approximate actual presence at the remote task site. Even the most advanced tele-operator systems will entail a certain degree of mismatch between the operator's action and resulting perceptual feedback. Procedures for facilitating adaptation to this altered perceptual-motor situation must be designed and tested. The Directorate has begun analyzing the sensory-sensory and sensory-motor mismatches that may remain for the tele-operator. Procedures for facilitating his/her resolution of these conflicts by means of adaptation will be devised and tested. Well-known principles of adaptation to sensory rearrangement will be applied in these training procedures.

Research is under way on information systems for exploration applications including real-time control of intelligent robotic systems and operations for an autonomous planetary rover. Through the development and use of intelligent robotics, an astronaut will be able to accomplish a much larger set of complex tasks as opposed to the execution of repetitive, labor-intensive tasks. The research effort concentrates on the real-time control and task planning for mobile, cooperating, two-arm robots (ref. 29). Research is also directed at the development and implementation of object-level control and execution including user-friendly operator interfaces. Object-based control using cooperating manipulators located on a flexible mounting base provides the capability to investigate and simulate many of the dynamic effects associated with the Flight Telerobotic Servicer (fig. 18). The research will provide the basic infrastructure for the development and control of two or more cooperating, two-arm robots performing interactive construction, assembly, and servicing tasks.

One objective of the research under way is to integrate virtual workstation interfaces with remote cameras for use in supervisory control of telerobots. Components of the interface include head-mounted visual displays and head-coupled stereo camera systems, 3-D auditory displays, limb position sensing, speech recognition, advanced pointing, object manipulation, and data-entry subsystems. Emphasis is on providing remote camera imagery that is matched to the capabilities and limitations of the human operator.

Future exploration missions will require systems that are able to plan and react to uncertain and changing environments. Furthermore, those missions will be extremely long. Software architectures are being developed that combine planning, plan-execution monitoring, and dynamic re-planning as

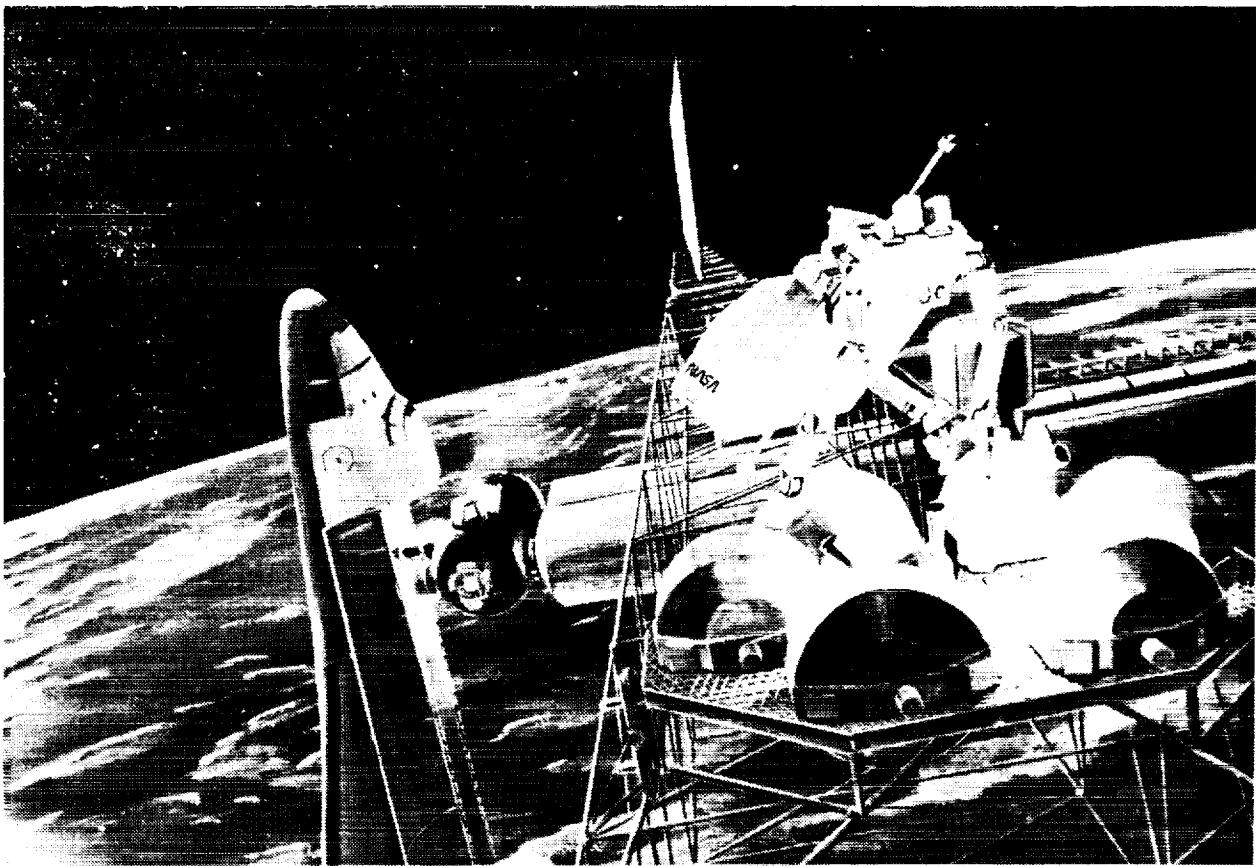


Figure 18. Flight tele-robotic servicer.

necessitated by unforeseen changes in the environment (ref. 30). Possible applications of intelligent systems include spacecraft fault diagnosis and isolation and recovery systems that are able to autonomously and safely modify their behavior in response to long-term spacecraft changes. They can also be applied to planetary rovers to enable them to simultaneously carry out navigational and scientific tasks.

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## **GOAL 2 SPACE—SPACE STATION FREEDOM**

**Develop new technologies for Space Station Freedom operations, evolution and growth to decrease life-cycle cost, and increase crew time available for performing experiments; develop new technologies to increase functional capabilities; and use Space Station Freedom as a laboratory for research and technology development.**

### **Human-Centered Design**

Human productivity can be improved in Space Station Freedom by taking into account human capabilities and limitations in the design of hardware elements with which humans are expected to interact for operation or maintenance. The Directorate provided a human factors-oriented design for the on-board payload control workstation and studied space-station architecture and geometry with the goal of applying human factors principles to space station designs. The workstation is an operational component of the Space Station United States Laboratory Module, which mission and payload specialists will use to control and monitor critical functions of payload hardware. It provides a video-conference, video-plexing, and data-networking facility for the crew of payload and mission specialists to hold “office hours” with Payload Mission Control and the experimenters on the ground. The Directorate provided the design of the workstation prototype with a deployable video conference table called a Wardroom Table (fig. 19). The Wardroom Table is a central fixture of the Wardroom, and adjusts to the full range of crew anthropometric body sizes and ergonomic reach envelopes in zero gravity (refs. 31 and 32).

Results of Directorate studies of various triangular-tetrahedral structural geometries found their way directly into the Space Station Freedom designs (ref. 33). The triangular and tetrahedral geometries emphasize the importance of the shortest possible “racetracks” for crew egress from modules and of circulation through the space station. The study recommended the use of connecting spherical nodes to join the components of the space station. Space Station Freedom design uses interconnect nodes, and retains the spherical geometry for the hyperbaric airlock. The study presented the concept of a relocatable cupola for the crew to have a wide field of vision while conducting proximity operations or making other observations. Space Station Freedom’s current design includes two such cupolas attached to nodes.

### **On-Board Monitoring, Diagnosis, and Control**

Complex space-based systems, such as the Space Station Freedom’s Thermal Control System, require constant monitoring and control due to the dynamic nature of the parameters, system configurations, and changing component health with time. Current operational practices generally require human operators to scan the sensor telemetry and watch for deviations from expected performance. In real time, large-scale applications, such as the subsystems of Space Station Freedom, these current practices may be expensive because of the labor-intensive tasks associated with the activity. By automating the applicable monitoring, failure detection and identification tasks, and control functions, the need for direct human involvement is reduced and system robustness is improved. A

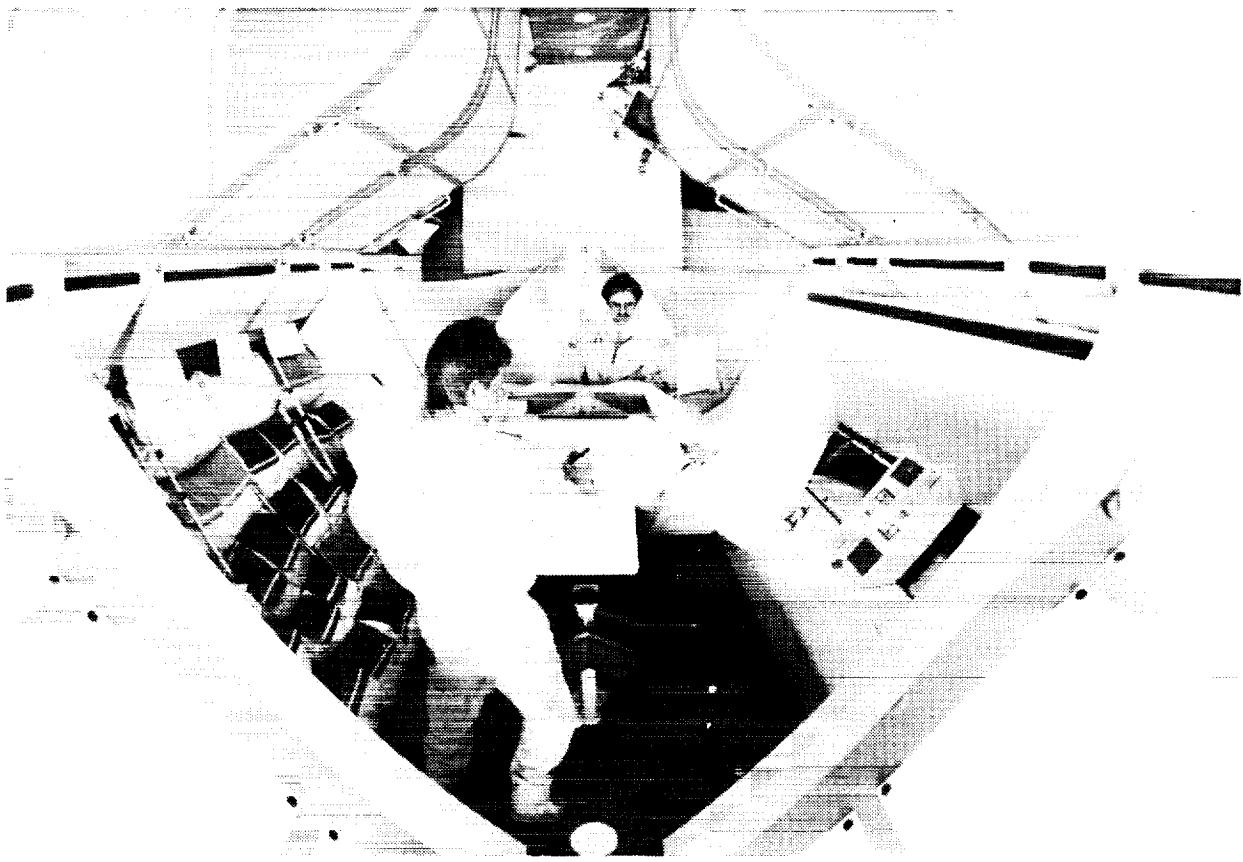


Figure 19. Wardroom Table.

symbolic, model-based reasoning approach to failure detection, identification, and control was demonstrated by an Ames/Johnson Space Center team for the advanced automated Thermal Control System (ref. 34). The Thermal Control System Testbed is illustrated in figure 20.

The Thermal Control System implementation provides the capability to autonomously follow changes in system parameters, in hardware configuration, and in sensor failures or sensor conflicts. The system uses an automated construction of a qualitative system-performance model. Operational robustness is greatly enhanced by the ability to operate and to reach, at least, partial conclusions in the absence of complete and/or inconclusive data. Future research will focus on improving the real-time performance of these knowledge-based methods, including the processing and understanding of multiple simultaneous faults in real time (ref. 35). We must also develop the human factors guidelines for design of on-board health-monitoring systems to ensure effective human intervention in off-nominal situations.

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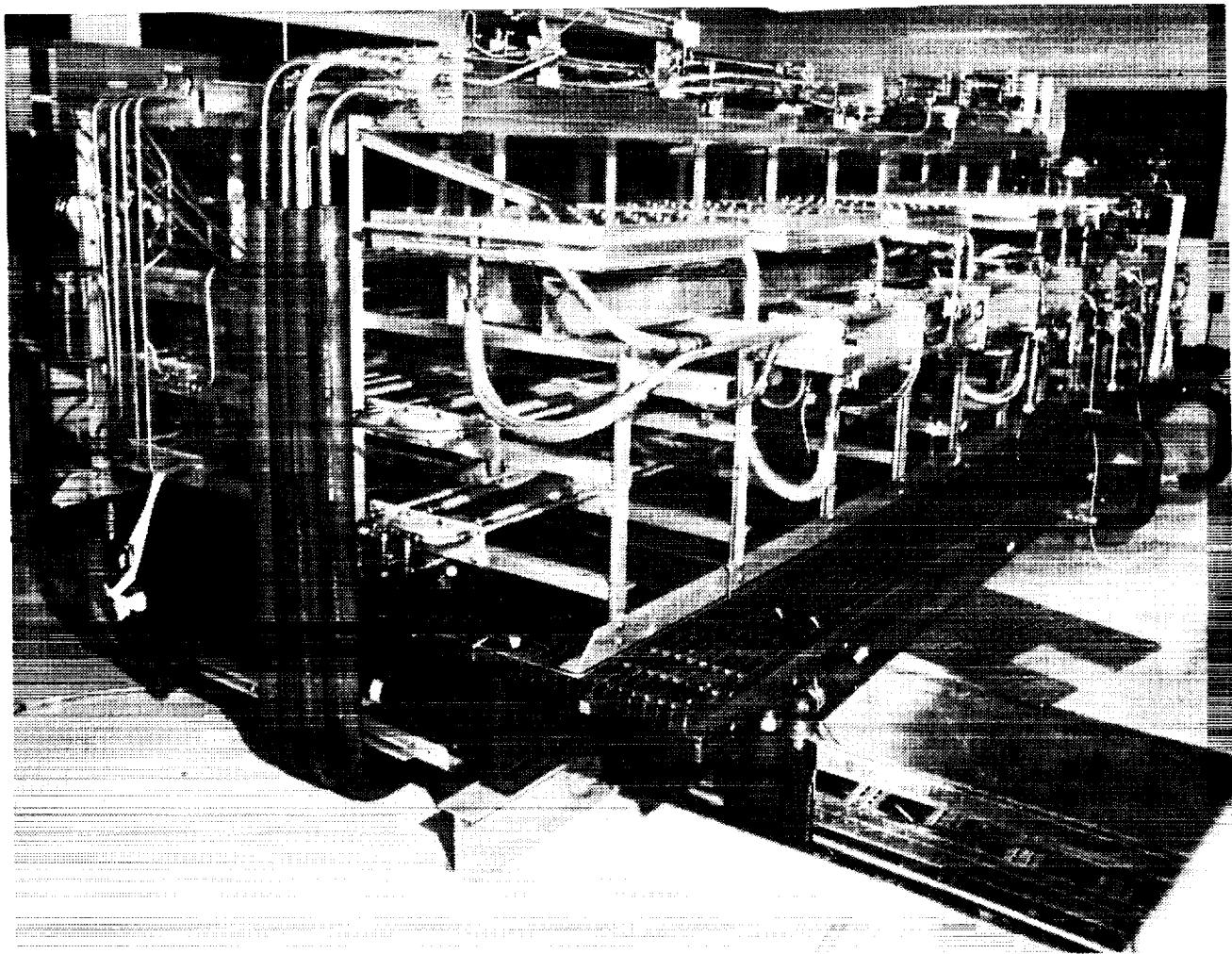


Figure 20. Thermal control system testbed.

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### GOAL 3 SPACE—TRANSPORTATION TECHNOLOGY

**Provide, by the mid-1990s, technologies to extend the capabilities of current space transportation systems, and, during the 1990s, develop new technologies for next generation vehicle systems with emphasis on maintainability and operability, safety and reliability, affordability and performance.**

The Directorate is providing technologies to enhance safety, reliability, operability, and performance, and to reduce costs of space-transportation systems. This includes research on human performance and information systems for space and ground operations.

## **Human Performance for Space and Ground Operations**

Human factors research is directed at improving the understanding of flight and ground-crew information and communication requirements. One area of research is to identify group communication patterns that facilitate effective information exchange both within teams and between interfacing teams. The initial phase of this project will focus on the cargo operations facility at John F. Kennedy Space Center (KSC). The current phase of research consists of developing a methodology and collecting preliminary data at KSC as a test bed for understanding the information management process and validating the methodology. The methodology developed could be used to improve the information management at KSC or other similar operations.

A research program is under way to develop computational models of human cognition (ref. 36) The objective of this research is to advance the use of artificial intelligence (AI)-based operator aiding systems through the in-depth analysis and modeling of a human-system interface. AI-based computational models of human cognition and information processing will be used to analyze the cognitive demands of the NASA Test Director station in the launch control center at KSC. The validated models will be used to provide functional specifications and techniques for assessing advanced launch concepts. Future launch concepts will include intelligent systems used to aid operators. Computational models that approximate aspects of human cognition can be used to assess the impact on the operator of proposed automation or other restructuring of launch-control-center operations.

## **Information Systems for Space and Ground Operations**

Many of the NASA scheduling problems require extensible systems that adapt quickly to changes in the specified problem. A current research effort concentrates on addressing the dynamic nature of scheduling problems, as well as the enormous search space normally encountered in such problems. Research emphasis is on the development of efficient algorithms for real-time rescheduling. Rescheduling algorithms have been developed that allow users to modify tasks in terms of their start and end times, their constraints, their resource requirements, and their durations (ref. 37). These algorithms are now being applied to improve scheduling of Space Shuttle processing at KSC.

A significant portion of the time and effort in developing large software systems for complex aerospace applications goes into the construction, verification, validation, and maintenance of the software algorithms. Typically, the software is custom-engineered for each specific application and is to be reused for the next application task. Rather than construct separate software systems for each task, it is desirable to develop and construct a large, reusable library (data base) of software modules. These modules contain the substance of several generic tasks and can support multiple applications.

Research efforts under way are focused on the development and utilization of multi-use knowledge bases containing a library of multiple software modules correlated with specific technical domains (ref. 38). Also, algorithms are being developed and implemented to apply the validated software modules to each mission application. Overall potential benefits of this research include improved run-time performance, increased robustness, reduced system software costs (both in construction and maintenance), and enhanced system reliability.

## GOAL 4 SPACE—SCIENCE

**Develop advanced observation, information, spacecraft, and operations technologies to maximize the return from NASA space and Earth science missions during the next 20 years.**

### Management and Analysis of Science and Engineering Data

NASA has many large unanalyzed data bases that could benefit from a high performance, validated, automatic classification system. The main goal of automatic classification and theory formation is the modeling of observed phenomena. Bayesian learning is a form of statistical learning that is particularly good at finding patterns in noisy data. In addition, Bayesian theory can guarantee that the patterns found represent a real effect operating in the data and not an artifact of the data analysis.

An automatic classification program known as Autoclass III has been developed and is sufficiently mature so that it can be applied to many different data bases (fig. 21). Autoclass III can find

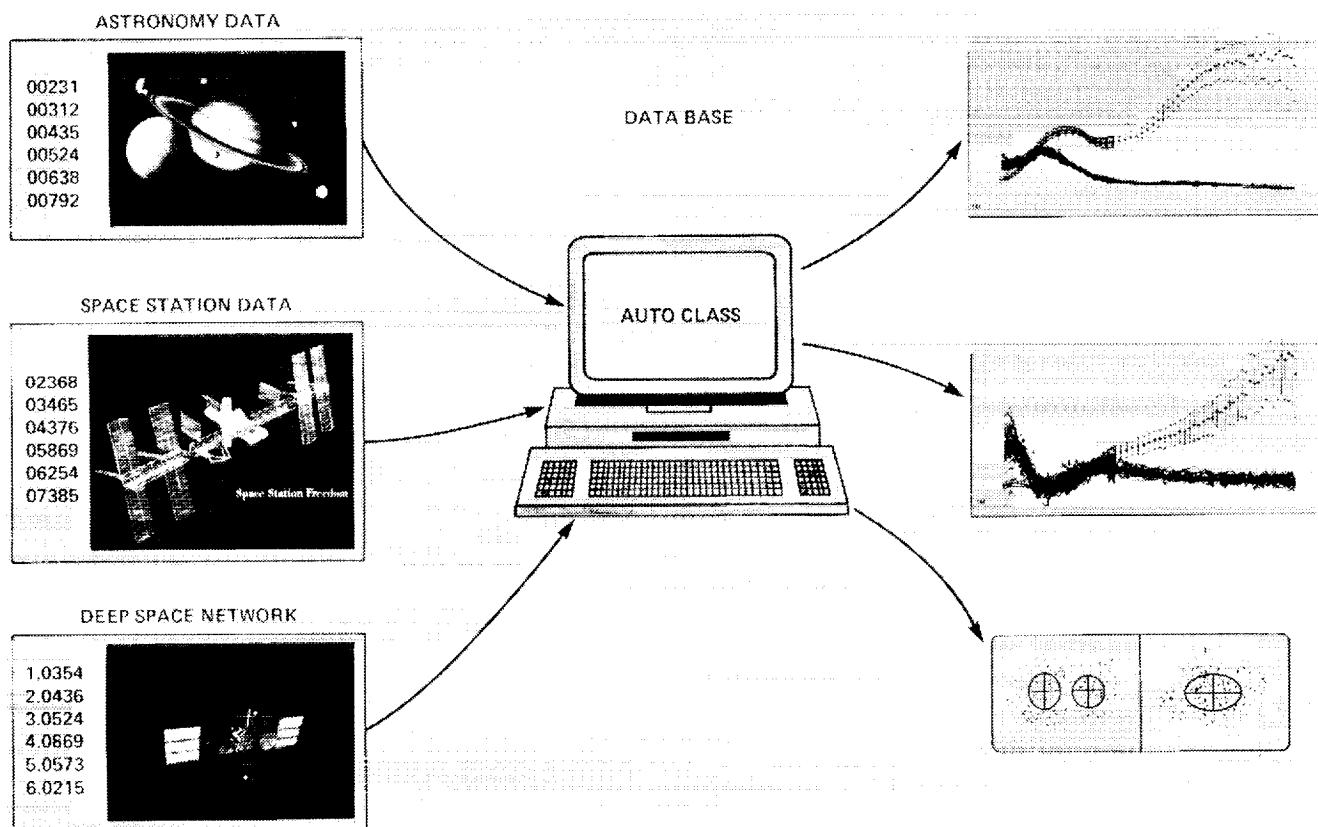


Figure 21. Autoclass III – Automatic Classification.

classes with a combination of real-valued and discrete data without any prior information concerning the availability of the classes present in the data. Unlike previous automatic classification programs, Autoclass III does not need to be told how many classes are present, or even if there are any classes at all. The software system uses a new extended Bayesian approach that searches for the most probable classification. Autoclass III has been applied to the Infrared Astronomical Satellite (IRAS), low-resolution, spectral data base containing infrared spectra for over 5,500 stars (ref. 39). The resulting classification included many well-known classes of stars as well as new classes of subtly different spectra of considerable astronomical interest.

Planetary physicists commonly use complex numerical models to aid in the prediction and analyses of the composition of planetary atmospheres. Unfortunately, a thorough understanding of the technical details of the software program implementing the model is required before the model can be used effectively to solve a problem. As a solution, a research effort is under way to develop an intelligent graphical interface that permits the scientists to inspect an atmospheric model, construct, modify parts of the model, execute the model, and perform analyses of the results (ref. 40). The intelligent interface uses object-oriented modeling techniques to develop a high-level atmospheric modeling language that resides at a level of abstraction above the basic programming language.

The conduct of experimental science in existing space-borne laboratories, such as Space-Lab, is severely constrained in several respects. The principal investigator is not normally on the spacecraft, and communication with the ground is often limited in data bandwidth and availability. Free discussion and decision making regarding experimental alternatives are inhibited. Ability and training of the astronauts in the specific scientific experiment are frequently limited to the training received just prior to flight. To minimize the consequences of these constraints, research is under way to develop and validate, via a flight experiment, a knowledge-based system that can carry on board much of the knowledge possessed by the ground-based principal investigators (ref. 41). The primary user of the system will be the astronaut performing the experiment, with occasional use by the mission manager and the principal investigator. The knowledge-based Astronaut Scientific Advisor will provide the following capabilities to advise and assist the astronaut performing the experiment: monitoring of signal quality, diagnosis of malfunctions, protocol management, quick-look data analyses, recognition of unusual and/or significant events, suggested protocol changes, and anticipation of additional resource requirements.

The Directorate is developing algorithms and methods applicable to NASA's data-intensive missions, such as the Space Station Freedom and the Environmental Observation Satellites. Research emphasis is on the three levels pertinent to high performance, multi-processing systems: representation level, control level, and processor level. The representation level deals with the knowledge and methods to solve the problems and the means to represent the solutions. The control level is concerned with the detection of dependencies and parallelism in the algorithmic and the program representations of the problem, and the synchronization and scheduling of concurrent tasks. The processor level addresses the hardware and the architectural components needed to evaluate the algorithmic and programmatic representations. Application focus for the research will be the Mission to Planet Earth due to the existing close interaction with the user community of the data collected during these missions.

## **GOAL 5 SPACE—BREAKTHROUGH RESEARCH**

**Advance high-payoff, highly innovative technology concepts that could provide revolutionary improvements in space capability.**

### **Photonics**

The objective of this research is to develop and demonstrate photonic processing techniques for on-board, real-time, image-processing tasks for applications to both science and engineering missions (fig. 22). Research emphasis is on the development and demonstration of real-time embedded image processors using an analog optical processor integrated with conventional digital processors (ref. 42). Using a new type of optical filter capable of recognizing objects over a range of views, hierarchical filter data bases have been developed and demonstrated. The optical filter is capable of recognizing a target object regardless of its orientation. Currently, the filter hierarchies developed in the laboratory demonstrate the near-term potential for high throughput from optical analog processors performing tasks in real time. Real-time applications include plume analysis and smart instrumentation of ground-based inspection and maintenance.

### **High Performance Computing**

High performance computing research consists of developing neural-network technologies and parallel processing techniques. Neural-network technologies are being investigated as a potential new approach which combines the responsiveness of a special-purpose processor with the general-purpose processor (ref. 43). Research is currently focused on two network designs: radial basis sparse distributed memory, and adaptive vector quantizers or self-organizing maps. The technology has potential applications to trainable controllers for robotic systems. Research is also being performed that will enable parallel processors to be used effectively for solving computationally intensive problems (ref. 44). The research effort is concentrated in four areas: compile time, run-time strategies for mapping parallel programs onto multi-processor simulation, visualization tools for performance prediction, and validation for the resulting mapping strategies. The results of these research efforts could lead to a thousand-fold increase in system performance.

### **Computational Vision**

Because newly developed imaging instruments are capable of producing more information than can be transmitted over radio links, there is great interest in new architectures for electronic transmission of visual information. Methods are being developed to reduce the volume of data which is transmitted, and to protect these data from the corrupting influence of the transmission without losing any real information. A perceptual components architecture for digital image communications has been developed based upon computational models of the human visual system (refs. 45 and 46).

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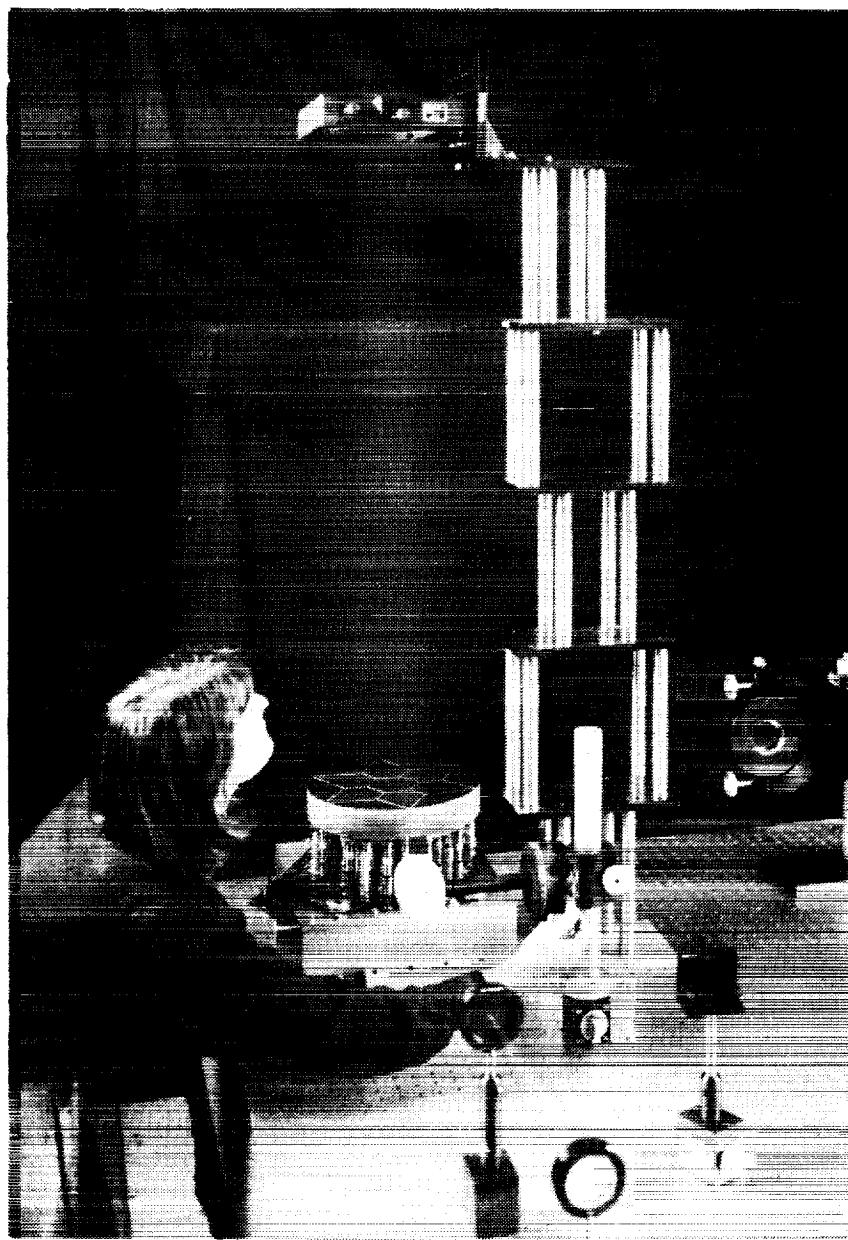


Figure 22. Optical image processing.

For data sets which are to be analyzed visually, bandwidth requirements are reduced by eliminating information which the human eye cannot perceive. The coding scheme is versatile, device-independent, efficient, and tolerant to noise and signal drop-outs. Ultimately, these codes lay the foundation for new standards in image communication systems.

## **Artificial Intelligence Research**

The Directorate's research in artificial intelligence focuses on three topic areas: planning and scheduling, machine learning, and design of and reasoning about large-scale physical systems (ref. 47). Research in the area of planning and scheduling is developing computer tools that decide on a sequence of actions to achieve a set of complex goals and determine how to allocate resources to carry out those actions. Research in the area of machine learning is developing techniques for forming theories about natural and man-made phenomena, and for improving the problem-solving performance of computational systems over time. Research in the design of and reasoning about large-scale physical systems is enabling the development of computer tools for knowledge acquisition, knowledge representation, and multi-purpose use of knowledge bases.

## **CONCLUDING REMARKS**

The Directorate's ability to perform research at all steps of the aerospace research process—from conceptual design, wind tunnel test, piloted simulation, to flight research—provides a rare capability to improve the design methodology for advanced aerospace systems. Having the various disciplines, aerodynamics, human factors, control and guidance, intelligent computational architectures, and artificial intelligence work together on common research problems, provides high payoffs from interdisciplinary synergistic effects and systems integration. This Directorate's research and development efforts in human factors and machine intelligent systems, as they apply to both aeronautical and space operations, provide a firm basis upon which to develop the understanding needed to design effective systems with which humans will interact to perform these missions.

Research activities under way today can lead to a revolution in both long- and short-haul aircraft, particularly in rotorcraft and powered-lift aircraft. Intelligent system technologies and automated controllers are becoming feasible and credible as they are demonstrated in real operational environments. Future civil and military aircraft will be designed to minimize pilot workload and pilot error via automation, leading to possible "robotic aircraft" and to space systems optimized for human productivity. Our research-and-development base puts us in a position to address human interactions with machines in complex real-world scenarios.

Research developments in areas of high-lift system aerodynamics, vehicle aeroacoustics, engine airframe integration, vehicle control and guidance, and conceptual design will provide the technology for new and improved aircraft of the 21st century. New aircraft and aircraft system technologies have great potential to expand the air transportation system, enabling achievement of projected growth, reducing congestion through new operating capabilities, and at the same time providing greater levels of safety and environmental compatibility.

The Directorate is laying the foundation for new opportunities to meet the challenges created by the human presence in space. Our developments and applications of new technologies in such areas as crew resource management, crew communication, crew training, habitat design, advanced visualization techniques, information systems, intelligent assistants, human-centered design

concepts, circadian dysrhythmia, human-machine interaction, and artificial intelligence all have direct and obvious application to the space-exploration missions. The plan is to adapt, apply, and extend our current knowledge base, methodologies, technologies, and facilities to the design of space systems with which humans interact to perform the space-exploration missions. The results will be information and guidelines to aid in designing human habitats, management environments, and intelligent machine systems that will provide optimal human interaction with automated systems and maximum human flexibility for command, control, communication, and scientific exploration.

The pursuit of the technologies for advanced aerospace systems is essential to a continued strong national posture. Because of the long lead time to move from research and technology development to the use of new technology, action is required now if the technologies projected are to be ready for use by the turn of the century. The Aerospace Systems Directorate will continue to pioneer new technology, create and capitalize on new opportunities, and be responsive to critical national aeronautical and space needs. The Aerospace Systems Directorate is prepared to meet the technical challenges and will continue to make significant contributions to the Nation's aerospace effort.

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16. Abstract <p>The Aerospace Systems Directorate is one of four research directorates at NASA Ames Research Center. The Directorate conducts research and technology development, for advanced aircraft and aircraft systems, in intelligent computational systems and in human-machine systems for aeronautics and space. The Directorate manages research and aircraft technology development projects, and operates and maintains major wind tunnels and flight-simulation facilities. This report describes the Aerospace Systems Directorate's research and technology as it relates to NASA agency goals and specific strategic thrusts as developed by the Office of Aeronautics, Exploration and Technology of NASA Headquarters and by the NASA research centers.</p>			
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